

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

re the Application of **Steinberg, et al.**

Application No.: 09/728,896 : Examiner: Michael P. Moon  
Attorney Docket No.: Shipley 03-05 : Group Art Unit: 2877  
Filed: December 1, 2000 :  
For: FIBER ARRAY SWITCH HAVING :  
MICROMACHINED FRONT FACE WITH :  
ROLLER BALLS :  
: *2877*

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**INFORMATION DISCLOSURE STATEMENT  
UNDER 37 C.F.R. § 1.97**

In compliance with the duty of disclosure set forth in 37 C.F.R. § 1.56, Applicants are submitting herewith a Form PTO-1449 and a copy of the references listed thereon. This Information Disclosure Statement is being filed after filing an RCE and before receipt of an Official Action in response to the RCE. Accordingly, it is believed that no fee is due. In the event that a fee is due, the Commissioner is authorized to charge any underpayment or credit any overpayment to Deposit account no. 04-1406.

The Examiner's attention is drawn to the following co-pending applications which are assigned to, or under obligation to be assigned to, assignee of the present applications. By disclosing the below listed applications applicants do not waive the secrecy of the applications.

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FIBER OPTIC ARRAY SWITCH (124)

Serial Number: 09/833,282

Filing Date: April 12, 2001

Inventor: Dan A. Steinberg

OPTICAL SWITCH ASSEMBLY WITH FLEX PLATE AND METHOD FOR  
MAKING (03-12)

Serial Number: 10/022,726

Filing Date: December 20, 2001

Inventors: David W. Sherrer, John Fisher and Dan A. Steinberg

OPTICAL WAVEGUIDE SWITCH (02-08)

Serial Number: 10/356,663

Filing Date: January 31, 2003

Inventors: Dan A. Steinberg; William T. Stacy; John J. Fisher; Mindaugas F. Dautartas and  
David W. Sherrer

OPTICAL WAVEGUIDE SWITCH (02-12)

Serial Number: 09/835,106

Filing Date: April 13, 2001

Inventors: Dan A. Steinberg and David W. Sherrer

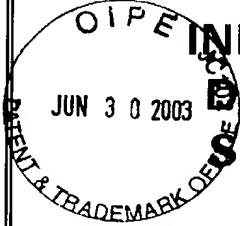
Applicants respectfully request full and proper consideration of the listed information during examination of the application, and that the listed information be printed on any patent that issues therefrom.

Respectfully submitted,

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 <p><b>INFORMATION DISCLOSURE STATEMENT</b></p>		<i>Complete if known</i>	
		Application Number: 09/728,896	
		Filing Date: December 1, 2000	
		First Named Inventor: Steinberg, et al.	
		Group Art Unit: 2877	
Examiner Name: Michael P. Mooney			
SHEET 1 OF 1		Attorney Docket Number: Shipley 03-05	

### UNITED STATES PATENT DOCUMENTS

EXAMINER'S INITIALS	CITE NO.	PATENT NUMBER	ISSUE DATE MM-DD-YYYY	FIRST NAMED INVENTOR

### FOREIGN PATENT DOCUMENTS

EXAMINER'S INITIALS	CITE NO.	DOCUMENT NUMBER	COUNTRY OR REGION	DATE OF PUBLICATION MM-DD-YYYY	FIRST NAMED INVENTOR OR APPLICANT
	B1	JP6385522	Japan	04/16/1988	Shinji Nagasawa, et al.

### OTHER PRIOR ART - NON-PATENT DOCUMENTS

EXAMINER'S INITIALS	CITE NO.	Include name of the author (in Capital Letters), title of the article (when appropriate), title of the item(book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published

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**EXAMINER:** Initial if reference considered, whether or not citation is in conformance with MPEP §609. Draw a line through citation if citation not in conformance and reference not considered. Include a copy of this form with next communication to applicant.

## Fiber Optic Array Switch

Dan A. Steinberg

Applicants claim the benefit of priority of U.S. Provisional Application 60/197,120, filed on April 14, 2000, the entire contents of which are  
5 incorporated herein by reference.

### Field of the Invention

The present invention relates generally to a fiber optic switch for selectively coupling at least one fiber of a first array to at least one fiber of a second array, and more particularly to a switch in which the arrays translate 10 relative to one another on friction reducing elements such as roller elements disposed within respective grooves of at least one of the arrays to switch the alignment of the at least one fiber of the first array relative to the at least one fiber of the second array.

### Background of the Invention

15 The need for switching to provide selective routing of information is becoming increasingly more important in optical data networks. In order to effect optical switching, different types of switches may be used which meet different performance criteria. For example, such switches may commonly be characterized by switching speed, coupling loss, and connectivity. In addition,

cost, reliability, and durability over switching lifetime are also important design considerations for such switches.

In certain applications, such as optical computer networks, high switching speed may not always be the most significant design criteria. In lieu of optimizing switching speed, such optical computer networks may employ inexpensive optical switches that are mechanically robust. As a result, the optical switches used in these types of optical computer networks may be mechanical in nature. Also, such switches should provide relatively high connectivity capability and minimal coupling loss between fibers. Such design goals, however, necessitate improved fiber to fiber alignment within the switch. Hence, it would be desirable to provide a mechanically robust switch, which is simple to assemble, and which provides improved fiber to fiber alignment resulting in decreased coupling loss.

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### Summary of the Invention

In accordance with the present invention, a fiber optic switch is provided for selectively coupling one or more fibers of a first array to one or more fibers of a second array. To this end, a simplified mechanical switching arrangement is provided for effecting improved registration between the selected optical fibers. The switch includes a first fiber array and a second fiber array each having a front face. The arrays are oriented so that the first array opposes the second array. The front faces of the arrays are disposed in facing relation. A friction-reduction element, such as a roller element, is positioned intermediate the opposing faces of the first and second array to enable the arrays to be displaced relative to each other along the friction reduction element.

Displacement of the one array relative to the other array causes a fiber in one array to be moved in or out of registration with a fiber in the other array to effect switching.

In a specific configuration of the switch, a first groove is disposed 5 within the front face of the first array. Optionally, a second groove is disposed within the front face of the second array. A roller element is located within at least the first groove but in friction reducing contact with the opposing second array thereby permitting the first array to translate relative to the second array along the direction of the longitudinal axis of the first groove. The second 10 groove may be positioned on the second array to oppose the first groove of the first array. As such, the roller element can be contained between the opposing grooves while providing friction reducing contact to the first and second arrays.

In a particular configuration, the arrays may be optionally oriented so that the grooves intersect one another at a selected angle, such as an orthogonal 15 angle, to enable translation of the arrays relative to one another in two directions. Further, detents may optionally be formed within the grooves to create regions in which the rolling element at least temporarily seats to properly position one array relative to the other array. The location and number of detents are arranged to correlate to the position and number of rows of channels 20 in the array, so that retention of the rolling element within the detents provides registration between fibers of the first and second arrays. Additional grooves and rolling elements may optionally be provided to enhance the stability between the first and second arrays, or to provide an additional direction of translation between the arrays.

### Brief Description Of The Drawings

The foregoing summary and the following detailed description of the preferred embodiments of the present invention will be best understood when read in conjunction with the appended drawings, in which:

5       Figure 1 schematically illustrates a cross-sectional side elevational view of a switch of the present invention;

Figure 2 schematically illustrates a front elevational view of an array of a switch of the present invention similar to the switch of Fig. 1 but with additional fibers and different types of rollers;

10       Figure 3 schematically illustrates an array having shortened grooves for retaining a roller element in place within the shortened grooves;

Figure 4 schematically illustrates the array of Figure 3 with an overlying complementary array, shown in phantom for purposes of clarity;

15       Figures 5 schematically illustrates an array having a groove configuration permitting array translation in two dimensions;

Figure 6 schematically illustrates a cross-sectional side elevational view of a switch of the present invention having detents within the grooves;

Figure 7 schematically illustrates a front elevational view of an array having detents within the grooves;

20       Figures 8 schematically illustrates an array having an array frame with passageways having different configurations and corresponding insert members having different configurations for insertion into the passageways of array frame for retaining fibers within the array;

Figures 9a and 9b schematically illustrate cross-sectional side elevational views of a MxN switch configuration of the present invention;

Figure 10 schematically illustrates a side elevational view of an array for retaining a partially un-jacketed fiber; and

Figure 11 schematically illustrates an exploded view of a switch of the present invention.

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### Detailed Description of the Invention

In accordance with the present invention, a fiber optic switch 100 is provided for selectively coupling outputs of one or more fibers 112 of a first array 101 to one or more inputs of fibers 112 of a second array 102. The selective coupling of fibers 112 is performed by displacing the arrays 101 and 102 relative to one another so that a selected fiber 112a of the first array 101 can be moved into alignment with a selected corresponding fiber 112b of the second array 102. Relative displacement of the fiber arrays 101 and 102 may be effected by translating one array relative to the other array. Translation may be effected by rolling action through the use of a roller element 106 serving as a friction-reduction element disposed between the two arrays. The roller element 106, such as a ball bearing in the form of a ball lens or rollable cylinder in the form of a fiber segment may be confined within complementary grooves 103, 104 of the respective array 101, 102. As shown in the exploded view of Fig. 11, a switch of the present invention having first and second arrays 1101, 1102 and 20 grooves 1103, with rolling elements 1106 sandwiched therebetween. As such, one array may be translationally rolled relative to the other array in a desired direction about the roller to effect the desired switching function. The complementary grooves in each array may be disposed, such as in parallel alignment, to define a single path of movement Alternatively, the grooves in the

two arrays may be disposed with intersecting paths, such as an orthogonal criss-cross, so that one array can be moved in one direction while the other array can be moved in another direction.

Referring to Fig. 1, the arrays 101, 102 include respective front faces 5 113, 114 and respective opposing rear faces 115, 116. Channels 107, 108 for retaining one or more fibers 112 extend through the body 118, or frame, of the arrays 101, 102, from the respective rear faces 115, 116 to the respective front faces 113, 114 of each array 101, 102. The grooves and the channels can be provided in the silicon substrate body 118 by a single mask technique, so that 10 the location of the roller elements 106 and the fibers 112 may be accurately determined.

The fibers 112 are disposed in the channels 107, 108 of the arrays 101, 102 and have endfaces 117 located at the exposed outer surfaces of the front faces 113, 114. The endfaces 117 of the fibers 112 may be perpendicular to the 15 optical axis of the fibers 112 or disposed at an angle with respect to the optical axis. In addition, the endfaces 117 of the fibers 112 of the array 101 may be flat and coplanar with the front faces 113, 114 of the respective arrays 101, 102. Typically, the channels 107, 108 are configured so that the optical axes of the 20 fibers 112 retained therein are generally perpendicular to the associated front faces 113, 114 of the arrays 101, 102.

As an exemplary application, the first array 101 may retain a single fiber 112a, in which case the second array 102 may include at least two fibers 112b and 112c between which the single fiber 112a may be selectively switched. Typically, the arrays 101, 102 each contain a plurality of fibers 112 which can 25 be arranged in a selected pattern, for example in a linear array, hexagonal grid,

or rectangular grid, as shown in Fig. 2, or in some other suitable pattern. For selected applications, the pattern of the first array may be different from the pattern of the second array. For example, the first array 101 may contain fibers 112 disposed in a linear array, while the second array 102 may comprise fibers 5 112 disposed in a grid pattern.

As shown in Fig. 1, the arrays 101, 102 are oriented with their respective front faces 113, 114 in facing relation. The front faces 113, 114 are typically spaced apart from one another to leave a small gap 110 between the first array 101 and the second array 102. The gap may typically be about 1 to 15 10 microns. To minimize coupling losses between fibers 112 of the first array 101 and fibers 112 of the second array 102, the gap 110 may be filled with a fluid having a refractive index closer to the refractive index of the fibers 112 than that of air. Ideally, the fluid in the gap 110 substantially matches the refractive index 15 of the fibers 112. Alternatively, a lens may be disposed at the fiber endface to improve coupling between a fiber 112 of the first array 101 and a fiber 112 of the second array 102. The spacing, or pitch, among fibers 112 of an array 101, as defined by the spacing among the channels 107 of the array 101, may be selected relative to the size of the gap 110 and the characteristics of the optional lenses to minimize cross-talk between fibers 112 not in registration.

20 In order to reduce frictional wear caused by translation of the arrays 101, 102 relative to one another, friction reducing slide elements, in the form of roller elements 106, are sandwiched between the opposing front faces 113 and 114 of the opposing arrays 101, 102. As shown in Fig. 1, a pair of roller elements 106 are confined within opposing longitudinal grooves 103, 104 25 disposed in the front faces 113, 114 of the frame 118 of each array 101, 102.

For purposes of providing smoother translation of one array relative to the other array, separate sets of grooves may be respectively provided on opposite sides of each respective front face 113, 114. The grooves 103, 104 may have a shape that permits the roller element 106 to roll along the path of the grooves 103, 104 as one array is translated relative to the other array. The path of the groove along the front face of any array defines the path of movement, both in terms of direction and distance, so that such array may be displaced relative to the other array. The groove path in any array thereby defines the switch path for such array. The groove path in any array must extend both in the direction and for the distance needed to effect the desired switching movement. For example, a fiber in a selected channel in one array must be capable of being moved in the desired direction and for the desired distance needed to position such fiber into respective registry for optical coupling with one or more fibers contained in selected channels in the opposing array.

Fig. 2 illustrates a view of the front face of an optical fiber array according to the present invention. As shown in Fig. 2, the array 102 includes two parallel grooves 104, 204 formed in the front face 114 of the array 102 along opposing edges of the front face 114. The grooves 104, 204 may have similar cross-sectional shapes or, as shown in Fig. 2, may have different cross-sectional shapes. For example, the groove 104 has a generally V-shaped cross-section to permit a spherical rolling element 106, such as a ball lens, to roll along the length of the groove 104. Alternatively, as shown in Fig. 2, the groove 204 includes a truncated V-shaped cross-section having a generally flat bottom in which a cylindrical roller element 206, such as a fiber segment, may slide or roll. A cylindrical shaped roller is useful in applications in which the arrays will

be translated only in a single linear direction transverse to the axis of the roller. The depth of the groove 104 and the diameter of the roller element 106 are selected relative to one another so that a portion of the roller element 106 protrudes outward from the front face 114 of array 102 a sufficient distance to 5 engage and hold the front face of the opposing array 101 either lightly in contact or preferably at least slightly out of contact with front face 114 of array 102.

The arrays 101, 102 are oriented with respect to one another so that at least a portion of their respective grooves 103, 104 are in registration. The alignment of the grooves 103, 104 of the two arrays 101, 102 permits one or 10 more roller elements 106 to be disposed simultaneously in the grooves 103, 104 of each array 101, 102. A bias force may be applied to the arrays 101, 102, by a mechanism such as a spring, to hold the arrays 101, 102 in facing relation to ensure that the rolling elements 106 are confined within the opposing grooves 103, 104 of the respective arrays 101, 102.

15 In a first configuration of the switch 100, the opposing grooves 103, 104 of the first and second arrays 101, 102 may be coextensive in both length and width. In such a configuration, the two arrays 101, 102 translate past one another in a single direction corresponding to the direction and the length of the grooves 103, 104. As the first array 101 translates relative to the second array 20 102, switching is effected by the alignment of fibers 112 of the first array 101 to corresponding fibers 112 of the second array 102. The lengths of the grooves 103, 104 are selected to permit a desired range of motion between the arrays 101, 102. For example, if each array comprises a grid of fibers 112, the respective grooves in each array should extend at least a distance corresponding 25 to the pitch of adjacent fibers to enable switching between adjacent fibers along

the path of the groove. To enable switching along an entire row or column of the grid, the grooves should span the full length of the grid, as shown in Fig. 2. Alternatively, if an array comprises a linear array of fibers arranged along a line orthogonal to the direction of translation, the groove may have a minimal length  
5 matched to the diameter of the roller element. In such a configuration, the array can be paired with a second array having a longer groove in the direction of the linear array and for the desired length of the linear array of fibers.

Additional grooves and roller elements may be included in the switch  
100 to provide added stability between the first array 101 and the second array  
10 102. For example, providing roller elements on both sides of the opposing arrays serves to eliminate potential tilting of one array relative to the other. The elimination of relative tilt between the arrays reduces the potential for misalignment between the fibers of the first array and the fibers of the second array. Since misalignment among fibers induces a coupling loss, it is desirable  
15 to remove degrees of freedom from the switch which are not associated with the switching function.

The paths of the grooves on the respective arrays function to define paths of movement for the switching function. In a configuration where  
20 translation between the arrays in only one direction is desired to effect switching, the array configuration may include two parallel, grooves 104, 204 each containing two roller elements 106, 206, respectively, as shown in Fig. 2. In such a switch, the four roller elements 106, 206 are positioned along the face  
114 of the array 102 to provide a stable support plane for the opposing array.

The improved stability provided by the additional roller elements 106,  
25 206 is based in part on their initial placement away from each other. However,

once the first array 101 has translated to the end of its range of motion with respect to the second array 102, the pairs of roller elements 106 and 206 may have the tendency of remaining in contact with one another. Subsequent translation of the arrays 101, 102 may not induce any separation between the 5 contacting pairs of roller elements 106, 206. Consequently, once the arrays 101, 102 have completed travel through the full range of motion, the added stability provided by multiple roller elements may be diminished unless the roller elements are held in separate positions within the grooves by detents, for example.

10           Alternatively, a different groove configuration, such as that depicted in Fig. 3, may be used to maintain spacing among roller elements 306. Instead of the single groove 104 depicted in Fig. 2, the array 302 of Fig. 3 includes a pair of grooves 304, 305 and 314, 315 in the front face of the array 302. More specifically, a shortened groove 305 in the form of a cavity and a longer 15 longitudinal groove 304 are formed along one side of the front face of the array 302. Likewise, a shorter groove 315 and a longer groove 314 are formed on the other side of the front face of the array 300. As shown in Fig. 3, the grooves 304 and 305 may be collinear. Alternatively, the shorter groove 305 may be offset or even disposed to one side of the longer groove 304. A roller element 306 is 20 disposed within each of the shorter grooves 305, 315, respectively, and each of the longer grooves 304, 314. The shortened grooves 305, 315 have a length and width substantially matched to a selected dimension of the roller element 306, such as the diameter of the roller element. The length and width of the shorter groove is selected so that the roller elements 306 may freely roll within the 25 shortened grooves 305, 315 without translating any significant distance within

the shortened grooves 305, 315. Translational movement of the roller element is confined to maintain a stable support plane provided by such roller elements for the opposing array.

As shown in Fig. 3, the first shortened groove 305 is disposed adjacent 5 the first longitudinal groove 304 and along the longitudinal axis of the first longitudinal groove 304. Similarly, the second shortened groove 315 is disposed adjacent the second longitudinal groove 314 and along the longitudinal axis of the second longitudinal groove 314. The longitudinal axes of the first and second longitudinal grooves 304, 314 are oriented parallel to one another.

10 The first set of grooves 304, 305 and the second set of grooves 314, 315 are respectively disposed on opposite sides of the fiber channels 308. In addition, the first shortened groove 305 and the second shortened groove 315 are disposed in diametrically opposite positions, i.e. at opposite corners, across the array of channels 308, as shown in Fig. 3. Roller elements 306 are confined for 15 rotational movement in each of the first and second shortened grooves 305, 315 and are confined for rotational and translational movement in each of the first and second longer grooves 304, 314.

Suitable structure may be provided to confine translational movement of the roller elements 106 within the longer grooves 304, 314 whenever the array 20 302 is translated relative to its opposing array to effect switching. For example, a suitable groove pattern may be provided on the opposing array which functions to confine any undesired translations movement of the roller elements 106 within the longer grooves 304, 314 of the array 302.

Referring now to Fig. 4, for example, a fiber array switch 300 is 25 diagrammatically depicted having the front face of an opposing array 301,

shown in phantom, positioned to oppose the array 302, shown in solid, in face to face relationship. The array 302, shown in solid, is identical to the array shown and described in connection with Fig. 3. The front face of the array 301, shown in phantom, is similar to the array 302 shown in solid. The front face of array 5 301 is shown in phantom to best depict the cooperation of the groove arrangement of array 301 relative to the groove arrangement of array 302. The cooperating grooves of the opposing arrays 301 and 302 function to retain the roller elements 306 in position generally at the outer periphery of the opposing arrays 301 and 302. As shown in Fig. 4, the roller elements 306 are confined at 10 the corners of the opposing arrays 301 and 302.

More specifically, the phantom array 301 is oriented so that the front face of such array 301 is in facing relation with the front face of the other array 302 to form a fiber array switch 300. The array 301, shown in phantom, includes a longer groove 1304 and a shorter groove 1305 positioned on one side 15 of the array and a longer groove 1314 and a shorter groove 1315 positioned on the other side of the array. The opposing arrays 301 and 302 are positioned in face to face relationship so that the one set of grooves 1304, 1305 of array 301 are aligned with complementary grooves 304, 305 of the other array 302 and so that the other set of grooves 1314, 1315 of array 301 are aligned with the 20 complementary grooves 314, 315 of such other array 302. The respective grooves are positioned so that the shorter grooves 305 and 315 of the one array 302 are positioned in different corners than the shorter grooves 1305 and 1315 of the phantom array 301. As such, on one side of the switch, the shorter groove 305 of array 302 faces and registers with an end portion of the longer groove 25 1304 of the phantom array 301 while an end portion of the longer groove 304 of

array 302 faces and registers with the shorter groove 1305 of such phantom array 301. On the other side of the switch, the longer and shorter grooves 314, 1315 of array 302 are aligned in a similar fashion with the shorter and longer grooves 1314, 1315, respectively, of the phantom array 301.

5           Thus, each of the four roller elements 306 is disposed within a shortened groove of one array and within a longer groove of the other array. Accordingly, the two roller elements 306 retained within the shorter grooves 305, 315 of the one array 302 are located in fixed position with respect to such array 302. Likewise, the two roller elements 306 retained in the shorter grooves 10       1305, 1315 of the opposing phantom array 301 are located in fixed position with respect to the phantom array 301. The roller elements retained in the shorter grooves 305, 315 are free to translate within the complementary longitudinal grooves 1304, 1314 of the phantom array 301. Likewise, the roller elements retained in the shorter grooves 1305, 1315 of the phantom array 301 are free to 15       translate within the longer grooves 304 of the first array 302.

          The switching function of the switch 300 is effected by translating the first array 302 with respect to the second array 301 along the direction of the longitudinal grooves 304, 1304. As the arrays are translated, each of the roller elements 306 will be retained in fixed relation with respect to either the first 20       array 302 or the second array 301. Additionally, the respective roller elements 306 will be held out of contact with each other as the arrays 302, 301 translate relative to one another.

          Alternative groove arrangements may also be provided to permit 25       translation of opposing arrays in two dimensions. Such an arrangement may include grooves disposed along two, non-parallel directions. For example, one

array may contain two grooves disposed perpendicular to one another to effect translation in each of the two perpendicular directions. One particular configuration of such an array is illustrated in Fig. 5.

The two dimensional array 502 includes a front face 503 having at least 5 a first groove 504 extending along a first path of movement. Additionally, a second groove 507 is positioned along the face at an intersecting path angle relative to the first groove 504 to provide a second path of movement. For the specific arrangement shown in Fig. 5, the array 502 includes pairs of orthogonal grooves 504, 507 formed therein in which one or more roller elements 506 are disposed. A pair of longitudinal grooves 504 extend along the edges of the array 10 502 to define a first direction of translation. A pair of cross grooves 507 are oriented perpendicular to the longitudinal axes of the longitudinal grooves 504. The cross grooves 507 define a second direction of translation which is 15 orthogonal to the first direction of translation. Optionally, only a single cross groove 507 may be used to extend away from a single longitudinal groove 504 in any non-parallel direction to create a second direction of translation.

As shown in Fig. 5, the cross grooves 507 have first ends in 20 communication with one longitudinal groove 504 so that the roller elements 506 disposed within such longitudinal groove 504 may translate relative to the cross grooves 507. The second longitudinal groove 504 is disposed parallel to the first longitudinal groove 504 at the opposite edge of the array 502. The second longitudinal groove 504 communicates with second ends of the cross grooves 507 to form a latticed groove path.

A plurality of channels 508 for holding optical fibers in a selected array 25 are disposed between the pair of longitudinal grooves 504 located at the edges of

the array. A number of the channels 508 may be disposed between the cross grooves 507 as shown in Fig. 5. Alternatively, all or none of the channels 508 may be disposed between the cross grooves 507. Similarly, a selected number of the channels 508 may be disposed between the first and second longitudinal grooves 504.

5 A fiber optic array switch may be formed using two identical arrays 502 disposed in facing relation so that the respective longitudinal and transverse grooves 504, 507 are in registration. The two arrays 508 are spaced sufficiently close so that the roller elements 506 are contained within the complementary 10 grooves 504, 507 of each array 502.

Still further, detents may be located within the grooves of opposing arrays to enable one array to be more precisely positioned relative to the other array. The use of cooperating detents in the opposing grooves of the arrays thereby facilitates more accurate registration between fibers of the first array and 15 fibers of the second array. Referring to Fig. 6, a fiber array switch 600 is shown comprising two arrays 601, 602 having grooves 604 which include detents 616. The switch 600, as depicted in Fig. 6, is similar to the switch 100 of Fig. 1, except that the array switch 600 shown in Fig. 6 includes two shorter grooves 604 in place of the single, longer groove 104 of switch 100 and detents 616 are 20 provided in the grooves 604.

As shown in Fig. 6, a pair of grooves 604 are formed in a front face 614 of the array 602 and extend along a common longitudinal axis. Likewise, a pair of complementary grooves 604 are formed in the front face 615 of the array 601. A roller element 606 is contained within each set of opposing complementary 25 grooves 604. A plurality of channels 608 for retaining fibers 612 extend from

the front faces 614 and 615 of each array 602 and 601, respectively, through the body of the arrays 602 and 601 to a respective rear face 618 and 617 of each respective array 602 and 601. Typically, each channel 608 has a longitudinal axis which is oriented perpendicular to the front faces 614 and 615 of the 5 respective arrays 602 and 601. Detents 616 are formed in the grooves 604 to provide recessed areas within the grooves 604 in which the roller elements 606 may temporarily seat. The detents 616 extend relative the front face 614 of the array 602 a distance greater than that of the grooves 604, so that the roller elements 606 may seat within the detents 616. The detents 616 may have a 10 generally triangularly shaped cross-section or may have alternative shapes suitable for retaining the roller elements 606 in place. For example, the detents 616 may have a generally rectangularly shaped cross-section.

In order to provide proper registration between fibers 612 of the first array 601 the fibers 612 of the second array 602, the detents 616 are spaced 15 relative to one another according to the pitch of the fibers 612 of the respective arrays 601 and 602. For example, the array 601 includes a preselected number of fibers 612 arranged in a column according to a preselected pitch along the direction of the longitudinal axis of the grooves 604. In turn, a number of detents 616 correlated to the preselected number of fibers in a column is 20 included within each groove 604. For example, as depicted in Fig. 6, three detents 616 are provided in each groove 604 for receiving the roller elements 606 in each respective groove. As such, the three detents in each groove directly correspond to the three fibers in the array column. In general, the spacing among the detents 616 preferably corresponds to the spacing among the fibers 25 612 of the associated array 602 and corresponds to the detents in the opposing

groove of the opposing array 601. Translational movement of the arrays 601 and 602 along the direction of the grooves 604 causes the roller elements to temporarily come to rest within opposing detents of the opposing arrays 601 and 602. Alignment of the opposing detents causes at least one fiber in one array 5 601 to align with a corresponding fiber of the other array 602.

Referring now to Fig. 7, detents 716 may also be disposed according to alternative configurations for purposes of enabling registration between fibers of two opposing arrays. The array 702 includes two parallel grooves 704 formed in a front face 714 of the array 702. The grooves 704 are located along opposite 10 edges of the front face 714 of the array 702. A plurality of fiber-retaining channels 708 are disposed in an array between the grooves 704. The channels 708 extend perpendicularly from the front face 714 through the body of the array 702. The channels 708 are disposed in a preselected number of rows, with each 15 row running perpendicularly to the grooves 704 and in a preselected number of columns running parallel to the grooves 704. The number of detents 716 should correspond either directly or indirectly to the preselected number of rows of channels 704. As shown in Fig. 7, the detents 716 are located in registry with each row of channels 708. The number of detents may indirectly correspond to 20 the number of rows by employing detents at every other row position in one groove and at every other intermediate row in the other groove. The detents 716 may have a shape similar to the detents 616 of the array 602 of Fig. 6.

The fiber-retaining channels of any array may be created using differing structures. In a first channel structure, as depicted in Figs. 1 and 2, the channels 108 comprise a cylindrical bore that extends through the body of the array 102

along a longitudinal axis that is perpendicular to the front face 114 of the array 102. Alternatively, as shown in Fig. 8, for example, fiber-retaining channels 808 may be provided by a series of fiber retaining grooves 822 formed along the base surface 839 of one or more passageways 818 passing through a frame 810 5 of the array 802. The passageways 818 extend from the front face 814 of the array 802 through the body of the array 802 and terminate at an opposing rear face of the array 802. The passageways 818 may extend a distance of about 200 to 1500 microns into the array 802, for example. The passageways 818 may have a generally rectangular cross-section taken in a plane parallel to the front 10 face 814 of the array 802. Alternatively, the passageways 818 may have different cross-sectional shapes suited to the retention of the fibers 812 in the array 802. An opposing fiber chip 820 is dimensioned for insertion into a cavity 818 in position to enclose the fiber retaining grooves 822 to create fiber channels 808, as shown in Fig. 8. Chip grooves 826 may be provided in the chip 15 820 so as to oppose and run coextensively, at least in part, with the retaining grooves 822 to form the fiber channels 808 therebetween.

More specifically, the chip 820 may include a series of grooves 826 disposed to form an edge having a generally crenelated cross-sectional shape. The grooves 826 extend from a front face 834 of the chip 820 through the body 20 of the chip 820 and terminate at an opposing rear face of the chip 820. Each groove 826 has a cross-sectional shape, such as a V-shaped cross-section, appropriate for retaining an optical fiber 812 in the fiber-retaining grooves 822 as depicted in Fig. 8. Other suitable shapes such as a rectangular, square, or circular shape, for example, may also be employed. The grooved chip 820 may 25 be used as a lidchip to engage the fibers 812 against the base surface 839 of a

grooved passageway 818. The grooves 822 on the base surface 839 may be provided as a separate basechip or may, as shown in Fig. 8, be provided directly on the base surface 839, which thereby functions as an integral basechip. Alternatively, a lidchip need not be used. Instead, the fibers 812 may be held in 5 place within the retaining grooves 822 using a suitable adhesive.

The front face 834 of the lidchip 820 may be disposed in a plane parallel to the plane of the front face 814 of the array 820. The front face 834 may also be disposed within the plane of the front face 814 of the array 820.

Alternatively, the front face 834 of the lidchip 820 may be recessed into the 10 interior of the array 820. The front face 834 of the lidchip 820 may also be disposed away from the fiber endface which lies proximate the plane of the front face 814 of the array 802.

The fiber-retaining grooves 822 may be disposed along one or more surfaces of the passageway 818 to form a passageway surface having a generally 15 crenelated cross-sectional shape. The fiber-retaining grooves 822 extend from the front face 814 of the array 802 through the body of the array 802 and terminate at the rear face of the array 802. Each fiber-retaining groove 822 has a cross-sectional shape appropriate for retaining an optical fiber 812, such as a V-shaped cross-section, as depicted in Fig. 8. Other shapes such as rectangular, 20 square, or circular shapes, for example, may also be used. For example, the shape of the fiber-retaining groove 822 may be selected to retain a polarization maintaining fiber, such as a polarization maintaining fiber having a triangular or D-shaped cross-section. The groove 822 may also optionally include a wick stop trench disposed within the base of the passageway internally of the array

802 to prevent the flow of an adhesive from the rear of the groove 822 to the front of the groove 822 located at the front face 814 of the array 802.

The passageways of any array may be identical to one another or may have differing shapes as depicted in Fig. 8. As an alternative to the fiber-retaining grooves 822, a different-shaped passageway 828 may include a generally flat bottom surface 830 against which the optical fibers 812 rest. Such a configuration may be particularly useful for retaining a fiber ribbon in place. Alternatively, a grooved lidchip 820 may be used to confine the fibers of the array within the grooves 826 of the lidchip 820 and against the flat bottom surface 830. In addition, to aid in the registration of the grooves, the passageway 828 may include at least one positioning probe 832 disposed on the base surface of the passageway for engagement with complementary sockets 831 of the lidchip 820. In particular, the probe 832 may be dimensioned to engage corresponding grooves 826 of the lidchip 820, which serves as the sockets.

As an alternative, a lidchip 821 without grooves may be employed to enclose the optical fibers 812 within the fiber-retaining grooves 822 on the base surface 839 of a passageway 818 to retain the optical fibers 812 in fixed position with respect to the array 802. The lidchip 821 may be held in fixed relation with respect to the fibers 812 and the array 802 using a suitable adhesive. The lidchip 821 is dimensioned to fit within the clearance of the passageway 818 and extends a sufficient length into the passageway to retain the fibers 812 within the fiber-retaining grooves 822. The lidchip 821 may have a generally rectangular solid shape with a generally flat fiber-engaging surface which abuts against the optical fibers 812.

In order to effect switching, the fiber array 802 comprises two longitudinally extending grooves 804 that are formed in the front face 814 of the fiber array 802. The grooves 804 are similar to the groove 104 described above with respect to array 102 of Fig. 2. The grooves 804 function to permit 5 translational movement of the array 802 relative to an opposing array to effect switching.

Referring to Fig. 10, individual fibers 1212 may be held in position within an array by the use of grooved basechips 1220 that are insertable into passageways 1218 through the frame 1215 of the array. In certain applications, 10 as shown in Fig. 10, the basechip 1220 may be configured to retain fibers 1212 wherein each fiber 1212 has a narrow fiber segment 1213 and an adjoining wide fiber segment 1211. The narrow fiber segment 1213 may comprise a clad core of an optical fiber and the wide fiber segment 1211 may comprise a jacketed fiber. Grooves 1222 in the basechip 1220 may be dimensioned to retain the 15 narrow fiber segment 1213 proximate the front face 1214 of the array 1202. The basechip 1220 may include a recessed area 1210 dimensioned to accept and hold the wide fiber segment 1211. The recessed area 1210 is provided at the end of the grooves 1222 disposed distal to the front face 1214 of the array 1202. As shown in Fig. 10, the recessed area 1210 extends deeper into the basechip 1220 20 than the grooves 1222 to accommodate the increased width of the wide fiber segment 1211. Grooves can optionally be provided in the top wall 1225 of the passageway 1218 to receive the fibers held by the basechip. Alternatively, the basechip 1220 can be inverted to serve as a lidchip for insertion into a passageway 818 of the array 802 of Fig. 8. Further, basechip and lidchip pairs 25 can be utilized for insertion into a passageway 1218. In such an arrangement,

fibers can be held between basechip and an enclosing lidchip within the passageway 1218.

The switch configurations described above may also be used to provide an MxN switch. In particular, Figs. 9a and 9b illustrate a 2 x 2 switch 900 of the present invention. The fibers 912a, 912b, 912c and 912d of the first array 901 are arranged so that the input and the output end of each fiber are disposed at the front face 914 of the array 901. Both ends of each fiber 912a, 912b, 912c and 912d are disposed within channels of the first array 901 so that the endfaces of the fibers are disposed proximate the front face 914 of the first array 901 to provide a loop back light path for each fiber. Thus, both ends of a selected fiber 912a of the first array 901 may communicate with respective fibers 112e and 912f of the second array 902. This arrangement effects communication between fiber 912e of the second array 902 and fiber 912f of the second array 902. Likewise, loop back fiber 912b of array 901 functions to connect fibers 912h and 912g of array 902.

As shown in Fig. 9b, as the first array 901 is translated with respect to the second array 902 into another switch position, the fiber 912e of the second array 902 is brought into registry with the fiber 912c of the first array 901. Fiber 912c of the first array 901 has both of its ends disposed within the first array 901 in a loop back fashion similar to that of fiber 912a. However, by locating the two ends of loop back fiber 912c at a spacing that is different than the spacing between the ends of loop back fiber 912a, loop back fiber 912c functions to bring fiber 912e of the second array into communication with a different fiber 912g of the second array 902 than fiber 912f. Likewise, loop back fiber 912d of array 901 functions to connect fiber 912h with fiber 912f of array 902.

The arrays described above may be fabricated of suitable materials in which the grooves, channels, passageways, and detents are formed. For example, one particularly suited material is single crystal Silicon which may be etched by isotropic or anisotropic processes to form the grooves. In particular, 5 grooves such as V-shaped grooves 104 or truncated V-shaped grooves 204 may be formed by anisotropic etching of Silicon. The channels and the passageways may be formed using reactive ion etching (RIE). In addition to RIE processes, other dry or wet physical/chemical etching processes, especially directional etching processes can be used to form the features of the array. In 10, addition, the grooves that retain roller elements may have a nitride coating to provide wear resistance and passivation.

It will be recognized by those skilled in the art that changes or modifications may be made to the above-described embodiments without departing from the broad inventive concepts of the invention. For example, the 15 switch can also comprise one or more waveguide chips instead of a fiber array. In such a case the switching is effected between waveguides in the waveguide chips. It should therefore be understood that this invention is not limited to the particular embodiments described herein, but is intended to include all changes and modifications that are within the scope and spirit of the invention as set 20 forth in the claims.

## Claims

What is claimed is:

1. A fiber optic array switch comprising:  
first and second substrates, each substrate comprising:  
a front and an opposing rear face, the front faces of each substrate disposed in facing relation to one another;  
at least one fiber-retaining channel disposed therein extending from the front face to the rear face; and  
at least a first groove disposed along a longitudinal axis within the front face; and  
at least one friction reducing element disposed within the first grooves of the first and second substrates, so that the first substrate may translate with respect to the second substrate along the direction of the longitudinal axis of the groove of the first substrate.
2. The switch according to claim 1 wherein the grooves are in registration.
3. The switch according to claim 1 wherein the grooves have the same length.
4. The switch according to claim 1 wherein the longitudinal axis of the first groove of the first substrate is orthogonal to the longitudinal axis of the first groove of the second substrate whereby the first substrate may translate with respect to the second substrate in a direction orthogonal to the longitudinal axis of the first groove of the first substrate.
5. The switch according to claim 1 wherein at least one groove of the first substrate is dimensioned to match a selected dimension of the friction reducing element so that the friction reducing element is confined within the groove of the first substrate.

6. The switch according to claim 1 wherein at least one of the grooves comprises at least one detent dimensioned to at least temporarily retain the friction reducing element at a selected position.

7. The switch according to claim 6 wherein the at least one fiber-retaining channel of the first substrate comprises a plurality of channels arranged in a preselected number of rows and wherein the number of detents in the groove of the first substrate is correlated to the preselected number of rows.

8. The switch according to claim 7 wherein the detents are spaced relative to the spacing among the rows of channels.

9. The switch according to claim 8 wherein the at least one fiber-retaining channel of the second substrate comprises a plurality of channels arranged in a preselected number of rows and wherein the number of detents in the groove of the second substrate is correlated to the preselected number of rows of channels of the second substrate.

10. The switch according to claim 9 wherein the detents in the groove of the second substrate are spaced relative to the spacing among the rows of channels of the second substrate, so that locating the friction reducing element in respective detents of the first and second substrates provides registration between respective channels of the first and second substrates.

11. The switch according to claim 1 wherein the first substrate comprises a second groove disposed within the front face of the first substrate.

12. The switch according to claim 11 comprising a second friction reducing element disposed within the second groove.

13. The switch according to claim 12 wherein the second groove is dimensioned to match a selected dimension of the second friction reducing element so that the second friction reducing element is confined within the second groove.

14. The switch according to claim 11 wherein the second groove is parallel to the first groove of the first substrate.

15. The switch according to claim 11 wherein the second groove is orthogonal to the first groove of the first substrate.

16. The switch according to claim 15 wherein the second groove communicates with the first groove of the first substrate.

17. The switch according to claim 11 wherein the second substrate comprises a second groove disposed within the front face of the second substrate.

18. The switch according to claim 17 wherein the second grooves of the first and second substrate are in registration and wherein the switch comprises a second friction reducing element disposed in the second grooves.

19. The switch according to claim 18 wherein the first and second substrates each comprise a third groove having first and second ends, the first end in communication with the respective first groove and the second end in communication with the respective second groove.

20. The switch according to claim 19 wherein the third grooves are perpendicular to the respective first grooves.

21. The switch according to claim 18 wherein the first grooves are in at least partial registration, and wherein the first groove of the first substrate is dimensioned to a selected dimension of the first friction reducing element so that the first friction reducing element does not translate within first groove of the first substrate, and wherein the second grooves are at least in partial registration and the second groove of the second substrate is dimensioned to a selected dimension of the second friction reducing element so that the second friction reducing element does not translate within the second groove of the second substrate.

22. The switch according to claim 11 wherein the at least one channel is disposed between the first and second grooves of the first substrate.

23. The switch according to claim 1 wherein the at least one channel of the first substrate comprises a linear array of channels.

24. The switch according to claim 23 wherein the linear array comprises a basechip having base grooves formed therein to provide the channels.

25. The switch according to claim 24 wherein the basechip is integrally formed with the first substrate.

26. The switch according to claim 24 wherein the linear array comprises a lidchip having lid grooves formed therein, and wherein the lidchip is positioned relative to the basechip so that the base grooves and the lid grooves are registered relative to one another to provide the channels.

27. The switch according to claim 26 wherein the basechip includes a probe and the lidchip includes a complementary socket for registering the basechip to the lidchip.

28. The switch according to claim 1 wherein the at least one channel of the first and second substrates each comprise a plurality of channels disposed in a two-dimensional array of channels.

29. The switch according to claim 1 wherein the at least one channel of the first substrate comprises a plurality of channels disposed in a two-dimensional array of channels.

30. The switch according to claim 29 wherein the two-dimensional array of channels comprises a plurality of linear arrays of channels arranged to provide the two-dimensional array.

31. The switch according to claim 30 wherein at least one of the plurality of linear arrays comprises a basechip having base grooves formed therein to provide the channels.

32. The switch according to claim 31 wherein the basechip is integrally formed with the first substrate.

33. The switch according to claim 32 wherein the linear array comprises a lidchip having lid grooves formed therein, and wherein the lidchip is positioned relative to the basechip so that the base grooves and lid grooves are registered to one another to provide the channels.

34. The switch according to claim 33 wherein at least one of the basechip and the lidchip includes a probe and at least one of the other basechip and lidchip includes a complementary socket for registering the basechip to the lidchip.

35. The switch according to claim 1 wherein the friction reducing element is substantially spherical.

36. The switch according to claim 1 wherein the friction reducing element is cylindrical.

37. The switch according to claim 1 wherein the friction reducing element has a circular cross-section.

38. A fiber optic array switch comprising:  
a first and a second fiber array, each array having a front face, the front faces disposed in facing relation to one another;  
a first groove disposed along a first path within the front face of the first array;  
a second groove disposed along the front face of the second array;  
and

a friction-reducing element disposed in the first groove and intermediate the front face of the first and second arrays to reduce friction between the first array and the second array as the first array is displaced relative to the second array to effect switching.

39. The switch according to claim 38 wherein the friction-reducing element includes a first roller element disposed within the first groove of the first array and in contact with the front face of the second array, so that the first array may be displaced relative to the second array along the direction of the first path.

40. The switch according to claim 39 wherein the second groove is disposed in opposing relationship with the first groove to provide a single path of relative displacement between the first and second arrays.

41. The switch according to claim 40 wherein the second groove is disposed relative to the first groove to provide more than one path of relative displacement between the first and second arrays.

42. The switch according to claim 41 wherein the first and second grooves are longitudinal grooves and wherein the second path provided by the second groove intersects the first path of the first groove at a selected angle to provide at least two paths of relative displacement.

43. The switch according to claim 42 wherein the longitudinal axis of the first groove is orthogonal to the longitudinal axis of the second groove, whereby the first array may translate with respect to the second array in a direction orthogonal to the first longitudinal axis.

44. The switch according to claim 39 wherein the first and second grooves are disposed to provide two-dimensional relative displacement of the first and second arrays.

45. The switch according to claim 39 wherein the first and second grooves have the same length.

46. The switch according to claim 38 wherein the first groove is dimensioned to match a selected dimension of the roller element so that the roller element is confined within the first groove during relative displacement of the first and second array.

47. The switch according to claim 38 wherein the first groove comprises at least one detent dimensioned to temporarily hold the roller element in a certain position within the first groove to permit the first and second arrays to be aligned relative to each other.

48. The switch according to claim 47 wherein the first array comprises a plurality of fiber channels arranged in a preselected number of rows of fiber channels, and wherein the number of detents in the first groove is related to the preselected number of rows of fiber channels.

49. The switch according to claim 48 wherein the detents are spaced relative to the pitch of the rows of fiber channels.

50. The switch according to claim 48 wherein the second array comprises a plurality of fiber channels arranged in a preselected number of rows of fiber channels, and wherein the second groove cooperates with the first groove of the first array and the second groove includes at least one detent, the number of detents in the second groove related to the preselected number of rows of fiber channels in the second array.

51. The switch according to claim 50 wherein the detents in the second groove are spaced relative to the pitch of the rows of fiber channels of the second array, so that locating the roller element in respective detents of the first and second arrays provides registration between respective fiber channels of the first and second arrays.

52. The switch according to claim 39 comprising a third groove disposed within the front face of the first array.

53. The switch according to claim 52 comprising a second roller element disposed within the third groove.

54. The switch according to claim 53 wherein the third groove is dimensioned to match a selected dimension of the second roller element so that the second roller element is confined within the third groove of the first array.

55. The switch according to claim 52 wherein the third groove is parallel to the first groove.

56. The switch according to claim 52 wherein the third groove communicates with the first groove.

57. The switch according to claim 56 wherein the third groove is orthogonal to the first groove.

58. The switch according to claim 52 comprising a fourth groove disposed within the front face of the second array.

59. The switch according to claim 58 wherein the first groove of the first array and the second groove of the second array are in at least partial registration to confine the first roller element.

60. The switch according to claim 59 wherein the third groove of the first array and the fourth groove of the second array are in at least partial registration and wherein the switch comprises a second roller element disposed within the third and fourth grooves.

61. The switch according to claim 52 wherein the first array includes a fifth groove having first and second ends disposed within the front face of the first array, the first end in communication with the first groove and the second end in communication with the third groove.

62. The switch according to claim 61 wherein the second array includes a sixth groove having first and second ends disposed within the front face of the second array, the first end in communication with the second groove and the second end in communication with the fourth groove.

63. The switch according to claim 39 wherein the first array comprises a plurality of fiber channels.

64. The switch according to claim 63 wherein the fiber channels of the first array comprise a linear array of channels.

65. The switch according to claim 64 wherein the first array comprises a chip having grooves formed therein to provide the channels for holding fibers of a fiber array.

66. The switch according to claim 65 wherein the first array includes a frame and a passageway through the frame and wherein the chip is insertable into the passageway of the first array.

67. The switch according to claim 63 wherein the first array includes a frame and a passageway through the frame and wherein the first array includes grooves in the passageway to provide the fiber channels.

68. The switch according to claim 67 comprising a chip insertable into the passageway to hold the fiber in the fiber channels.

69. The switch according to claim 67 wherein the first array comprises a chip having chip grooves formed therein, the chip being insertable into the passageway so that the chip grooves may register with the grooves of the passageway to provide the fiber channels.

70. The switch according to claim 64 wherein the first array includes a frame and a passageway through the frame and wherein the first array includes a chip insertable into the passageway to hold fibers in the fiber channels and wherein the first array includes a probe on at least one of the passageway and the chip and a complementary socket on at least the other of the passageway and the chip for registering the chip within the passageway.

71. The switch according to claim 64 wherein the fiber channels of the first array comprise a two-dimensional array of channels.

72. The switch according to claim 71 wherein the two-dimensional array of channels comprises a plurality of linear arrays of channels arranged to form the two-dimensional array.

73. The switch according to claim 39 wherein the roller element is substantially spherical.

74. The switch according to claim 39 wherein the roller element is cylindrical.

75. The switch according to claim 39 comprising optical fibers disposed within the first array.

76. The switch according to claim 39 wherein the first array holds at least one optical fiber.

### Abstract of the Disclosure

An optical switch is provided for selectively coupling outputs of one or more fibers of a first array to one or more inputs of fibers of a second array. The first array includes a first groove disposed within a front face of the first array. The second array optionally includes a second groove disposed within a front face of the second array. The first and second fiber arrays are oriented so that their respective front faces are disposed in a facing relationship. A roller element is located within at least the first groove, permitting the first array to translate relative to the second array upon the roller element along the direction of the first groove. In addition, detents may be formed within the grooves of each array to create areas in which the roller element may at least temporarily seat. The location and number of detents are arranged to correspond to the location and number of rows of fibers in the respective arrays. Retention of the roller element within a detent permits more accurate registration between fibers of the first and second arrays.

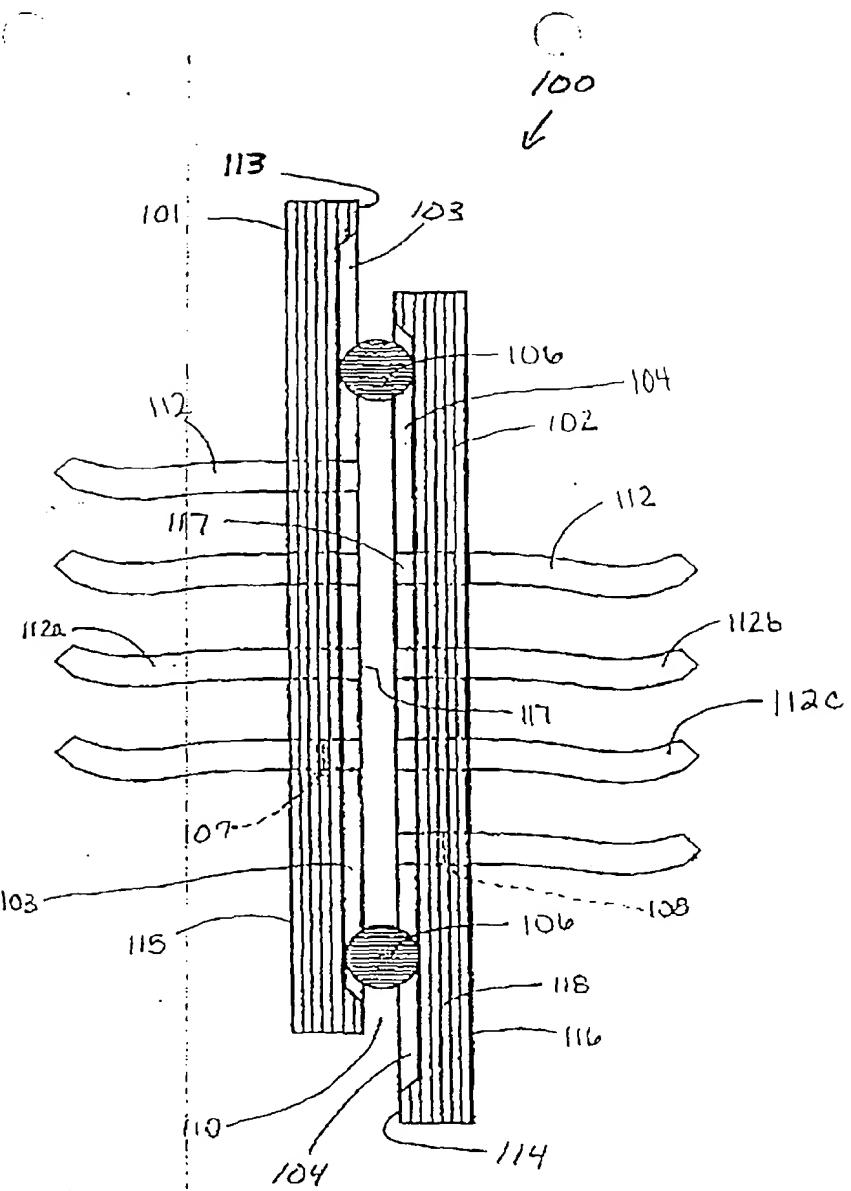


Fig. 1

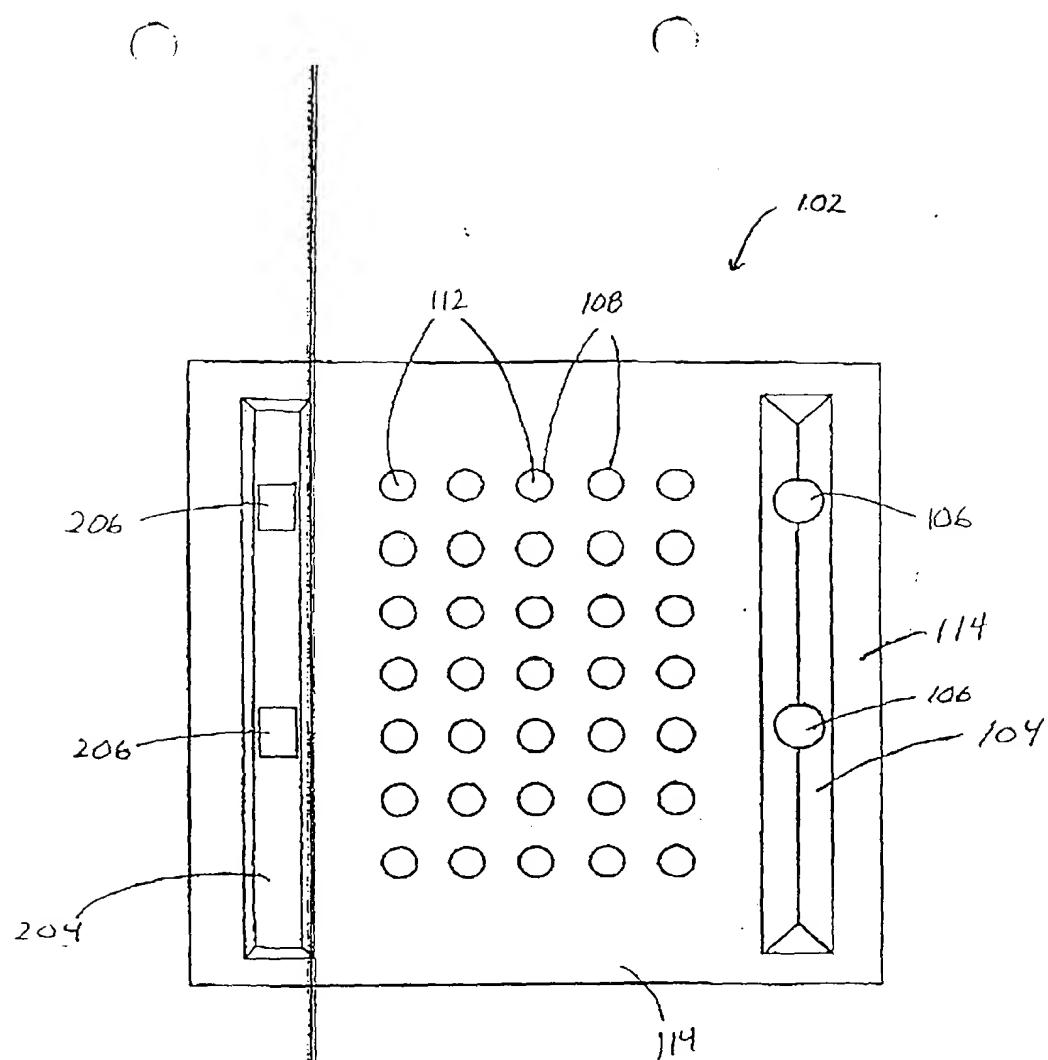
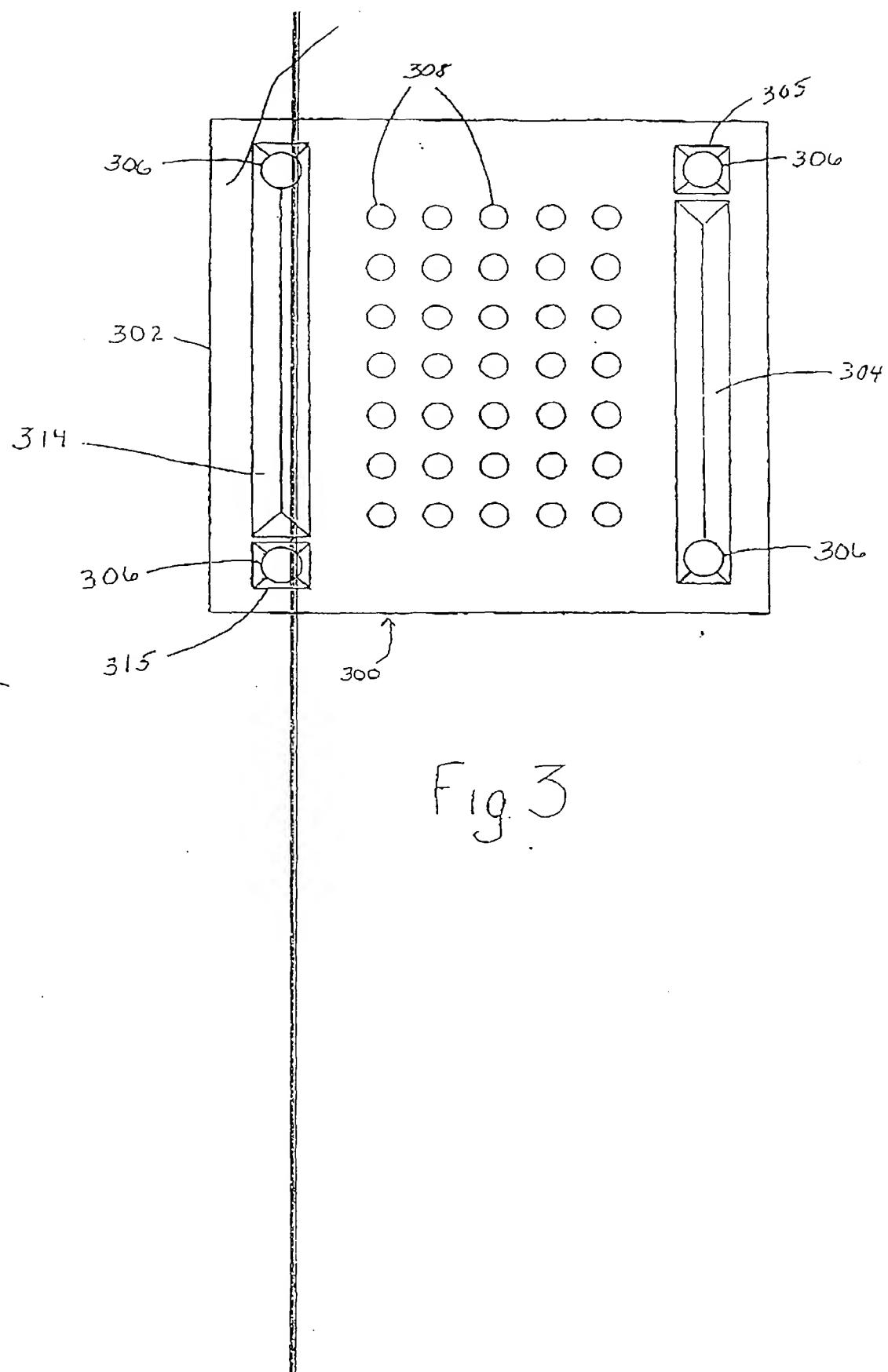
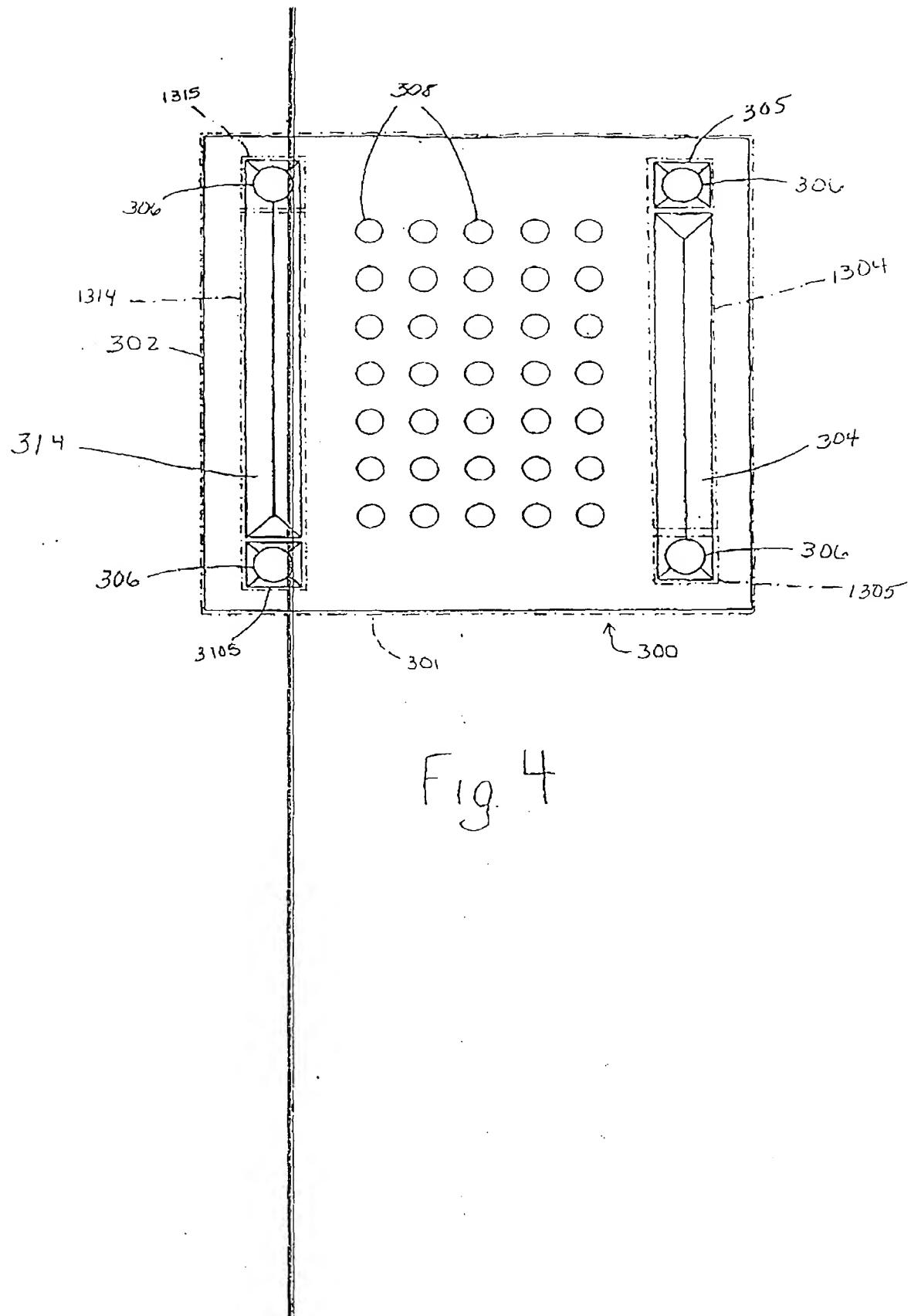


Fig. 2





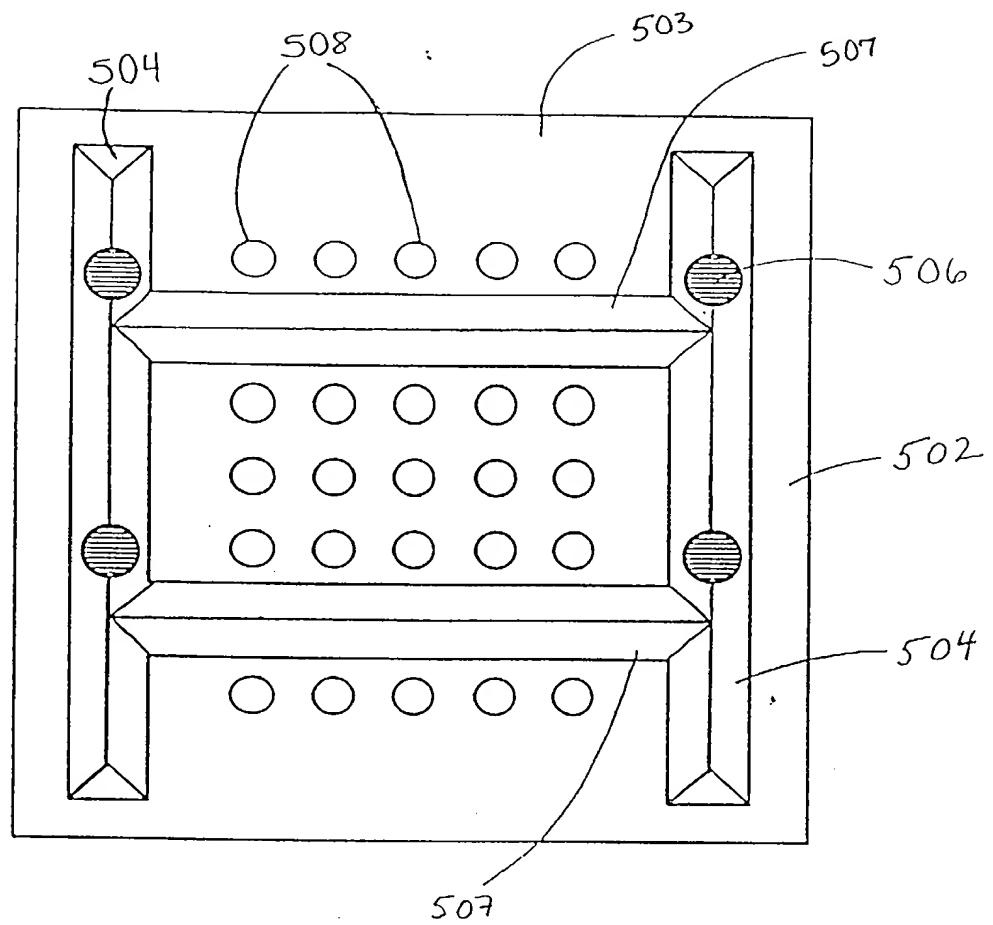


Fig. 5

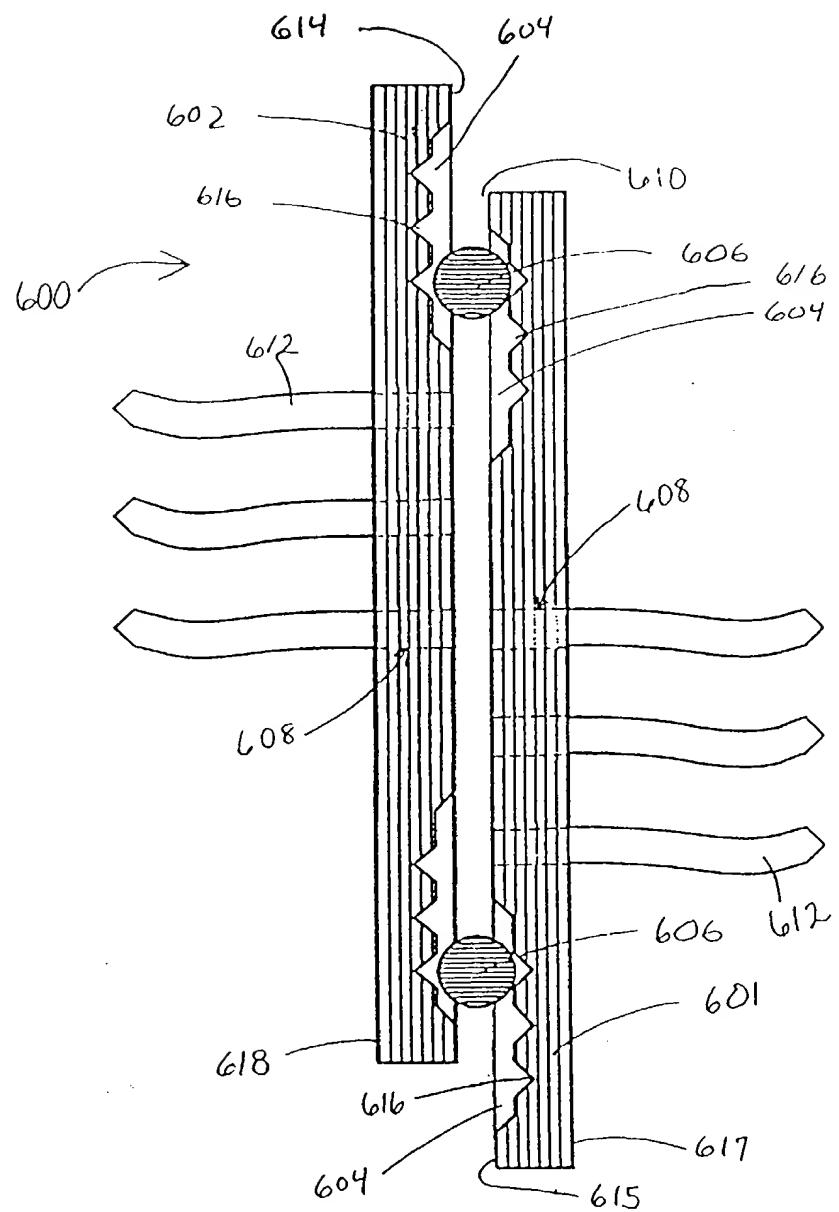


Fig. 6

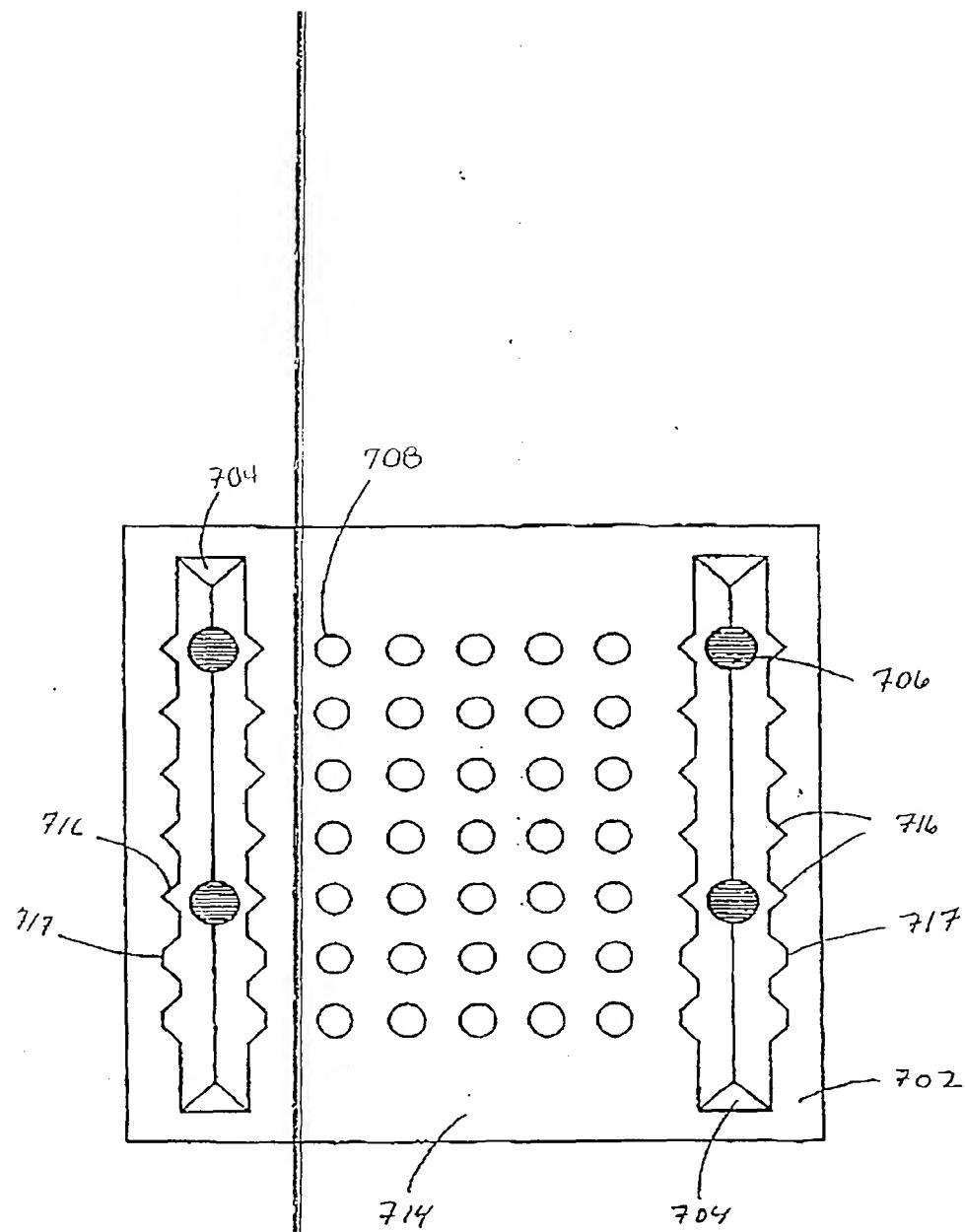
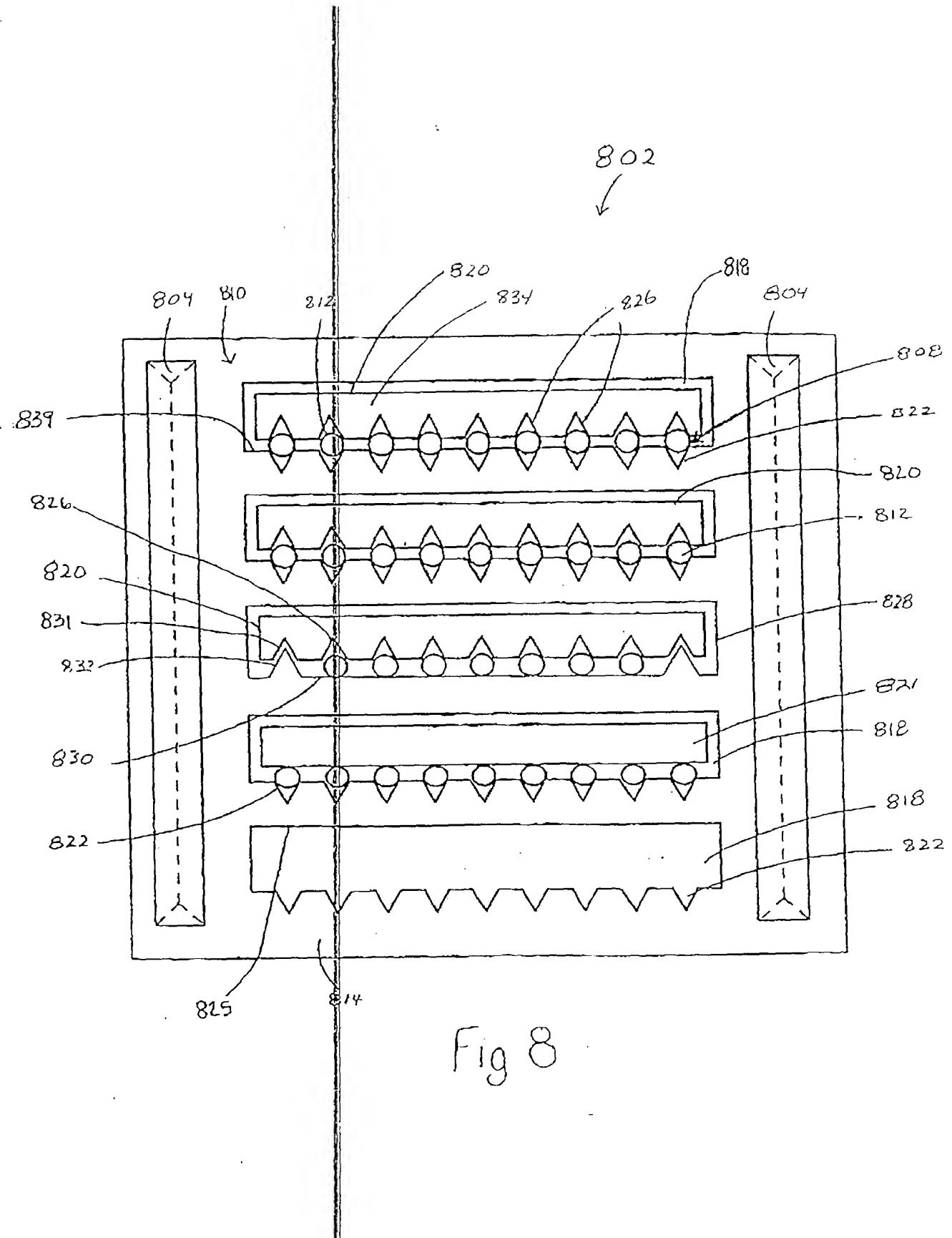


Fig. 7



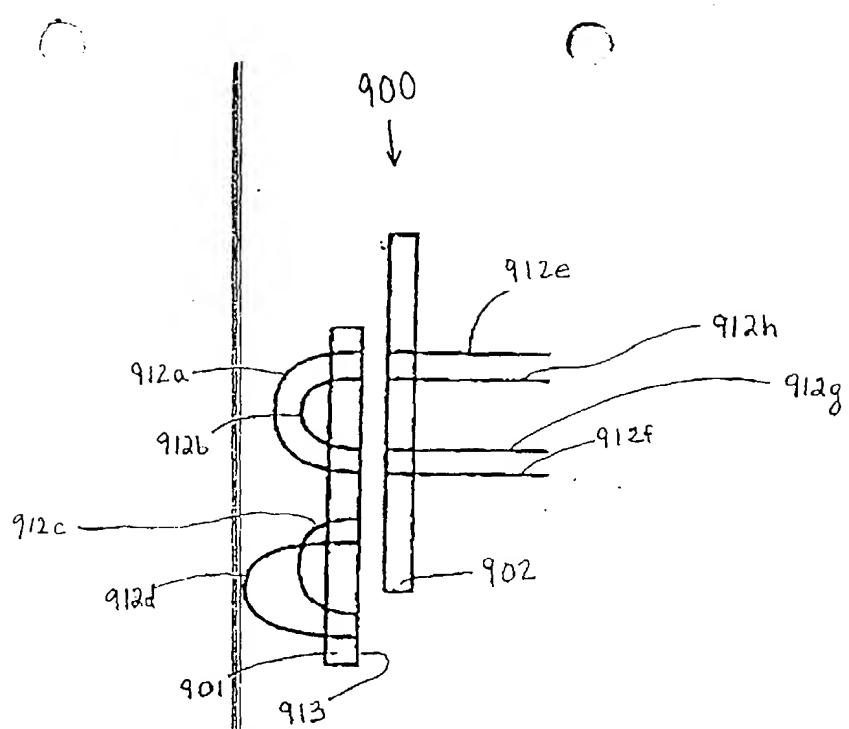


Fig 9a

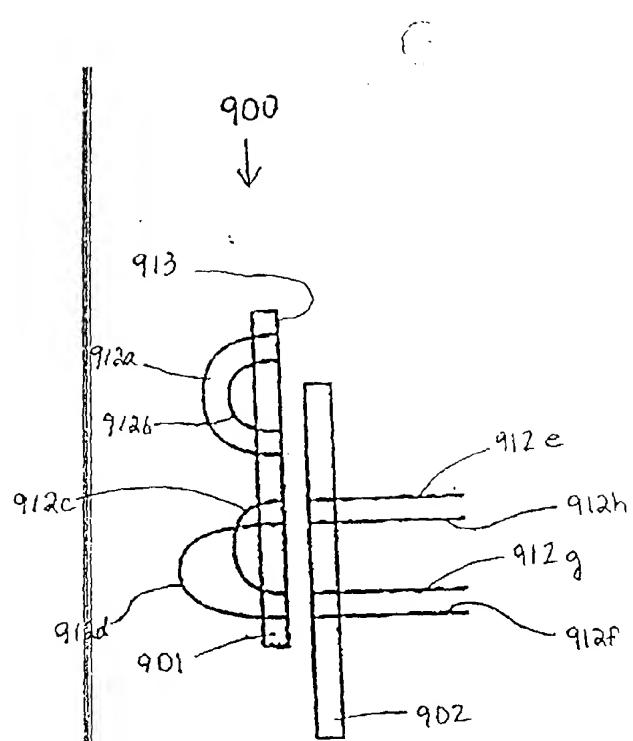


Fig. 9b

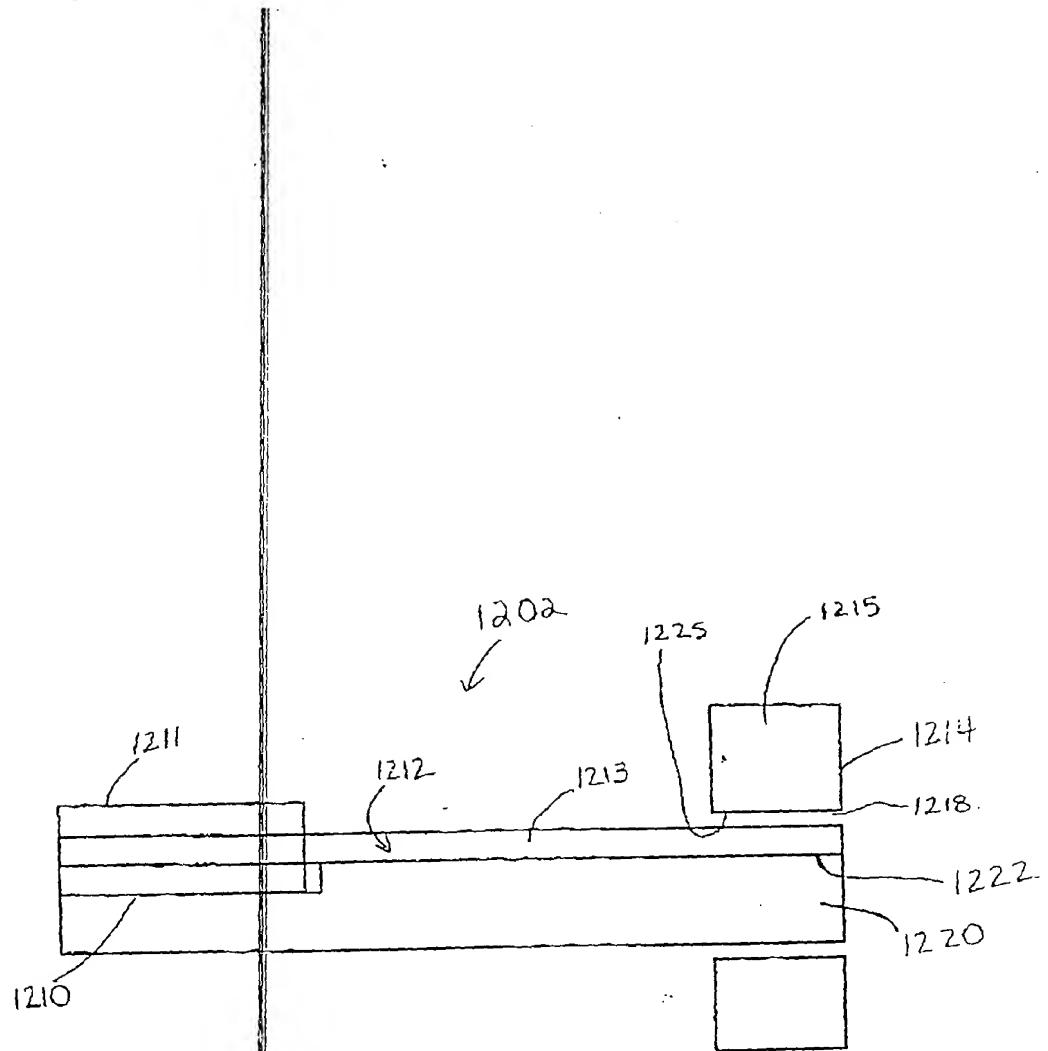


Fig. 10

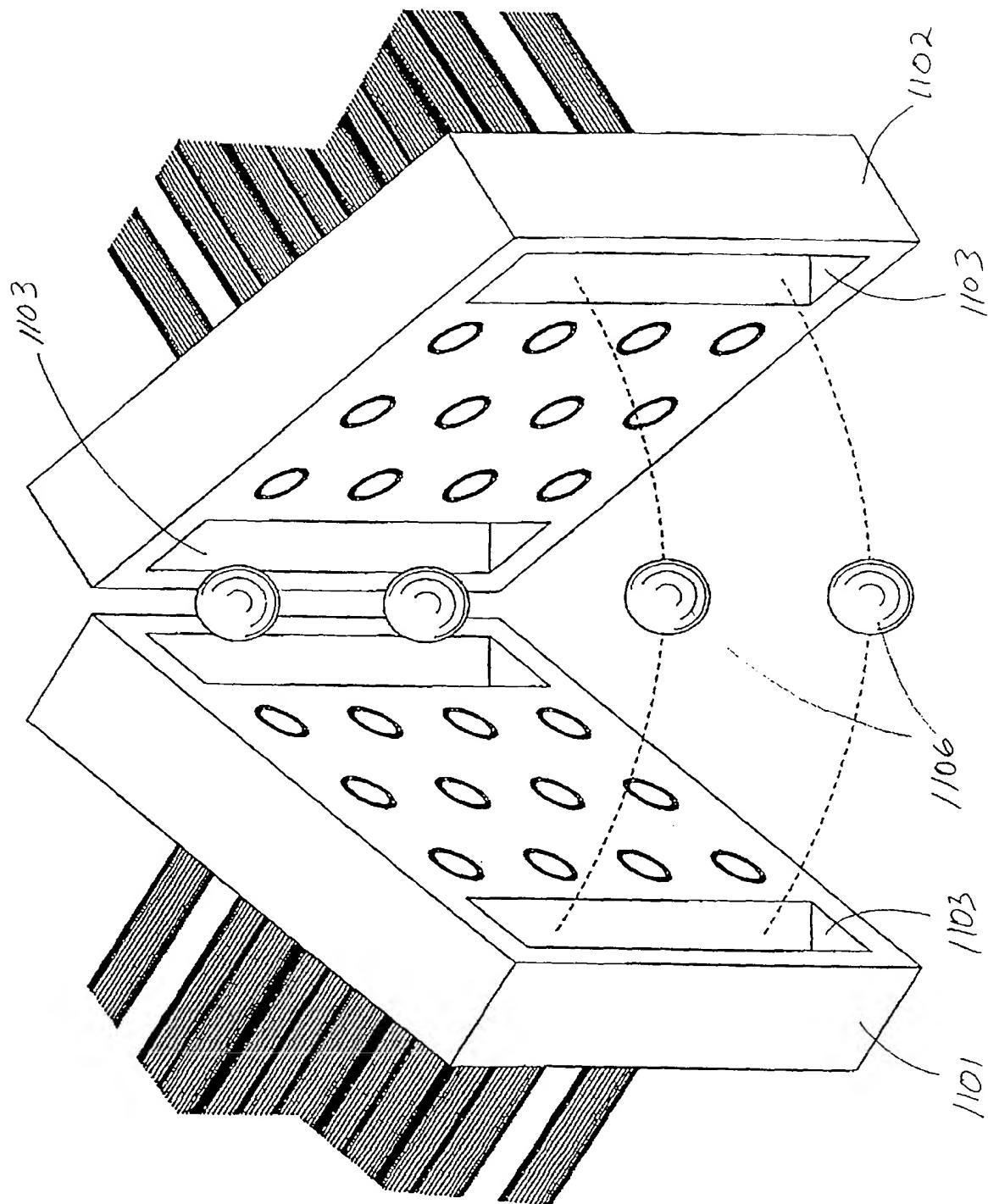


Fig. 11

upper right

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
APPLICATION FOR U.S. LETTERS PATENT

**Title:**

**OPTICAL SWITCH ASSEMBLY WITH FLEX PLATE AND METHOD FOR  
MAKING**

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## OPTICAL SWITCH ASSEMBLY WITH FLEX PLATE AND METHOD FOR MAKING

[0001] This application claims priority from provisional application serial no. 60/257,020, filed December 20, 2000, the entire disclosure of which is incorporated herein by reference.

### BACKGROUND

[0002] Conventional frustrated total internal reflection/total internal reflection optical fiber switches operate by displacing at least one of the fibers to contact, or come within less than a micron from contact with, the other fiber (closed position) or to release contact with the other fiber (opened position). Generally, the optical fibers connect one another at ends which are formed transverse to the longitudinal axis of the fibers and coplanar to one another. In the closed position, input light is transmitted from one optical fiber to the other with little or no transmission loss. In the opened position, in which a gap exists of greater than one micron between the optical fibers, input light is reflected from one of the fibers, leading to complete or partial transmission loss. Complete transmission loss occurs during total internal reflection, when light approaches a dielectric interface at or above a critical angle and is thereby suppressed from being transmitted to the other optical fiber. When the angle is below the critical angle, or the distance between the optical fibers is sufficiently small, some input light may cross the gap between the optical fibers and thereby frustrate the total

internal reflection. An example of such a conventional optical switch is described in U.S. patent numbers 5,390,266 and 4,176,908.

### SUMMARY

**[0003]** The invention provides an optical switch that includes first and second optical arrays separated by an interface, and a support structure upon which the optical arrays are mounted. The support structure includes an area which has a flexing profile that differs from the remainder of the support structure such that upon the operation of force on the support structure the optical arrays are optically coupled or decoupled.

**[0004]** The invention also provides an optical switch that includes first, second, third, fourth and fifth optical arrays and a support structure upon which the first, second and third optical arrays are mounted. The third optical array is interposed between the first and second optical arrays, the first and third optical arrays are separated by a first interface, and the second and third optical arrays are separated by a second interface. The support structure includes a pair of areas which each have a flexing profile that differs from the remainder of the support structure. The fourth optical array is positioned transverse to the first and third optical arrays in the vicinity of the first interface and the fifth optical array is positioned transverse to the second and third optical arrays in the vicinity of the second interface.

[0005] The invention further provides a method for assembling an optical switch. The method includes aligning at least a first optical array and a second optical array relative to one another with an alignment tool, positioning the at least first and second optical arrays on a support structure, immobilizing the at least first and second optical arrays relative to the support structure, and removing the tool from the at least first and second optical arrays.

[0006] The foregoing and other advantages and features of the invention will be more readily understood from the following detailed description of the invention, which is provided in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIGS. 1-3 is a side view of an optical switch assembly constructed in accordance with an embodiment of the invention.

[0008] FIG. 4 is a perspective view of the flex plate of the optical switch assembly of FIG. 1.

[0009] FIG. 5 is a side view of an optical switch assembly constructed in accordance with another embodiment of the invention.

[0010] FIG. 6 is a side view of an optical switch assembly constructed in accordance with another embodiment of the invention.

[0011] FIGS. 7-9 is a side view of an optical switch assembly constructed in accordance with another embodiment of the invention.

[0012] FIG. 10 is a schematic drawing of a conventional optical system.

[0013] FIG. 11 is a schematic drawing of an optical system utilizing the optical switch assembly of FIG. 7 in accordance with another embodiment of the invention.

[0014] FIGS. 12-13 are side views showing the assembly of an optical switch assembly in accordance with another embodiment of the invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0015] Referring to FIGS. 1-4, in which like numerals designate like elements, an optical switch assembly 10 is shown including a first optical array 11, a second optical array 21, and a flexible support structure, such as a flex plate 40. The first optical array 11 includes a support structure, such as a chip 12, that has a face 20 and first and second surfaces 14, 18. The first surface 14 includes at least one first surface groove 16. The second optical array 21 includes a support structure, such as a chip 22, that has a face 30 and first and second surfaces 24, 28. The first surface 24 has at least one first surface groove 26. The chips 12, 22 are preferably formed of silicon.

[0016] The flex plate 40 includes a trench 42 which is preferably formed through isotropic etching. Each of the optical arrays 11, 21 is mounted on the flex plate 40, which is preferably formed of single crystal silicon, such that there is an interface 25 between the faces 20, 30 and such that the interface 25 is positioned above the trench 42. The first and second arrays 11, 21 are positioned and adhered to the flex plate 40. Preferably an adhering material is utilized to immobilize the first and second arrays 11, 21.

[0017] Upon each of the optical arrays 11, 21 are mounted one or more optical fibers, which are preferably formed of silica. As shown, an optical fiber 32 is mounted within the groove 16 of the chip 12, and a corresponding optical fiber 36 is mounted within the groove 26 of the chip 22. The optical fibers 32, 36 have endfaces 34, 38, respectfully. The optical fibers 32, 36 may be adhered to the grooves 16, 26 through the use of an adhering material or mechanism (not shown). Any suitable adhering material or mechanism may be used, such as, for example, ultraviolet curable epoxy, solder, aluminum-oxide direct thermal compression bonding, or sol-gel or spin-on glass.

[0018] The optical switch assembly 10 is shown in FIGS. 2-3 in, respectively, an opened and a closed state. In FIG. 2, forces are directed upon the flex plate 40 at certain locations. Specifically, a force in a direction B is directed toward the flex plate 40 generally near the trench 42. Further, forces in a direction A are directed away from

the flex plate 40 at ends of the flex plate 40. The forces tend to allow the flex plate 40 to flex such that its ends move generally in direction A. Since the chips 12, 22 are mounted on the flex plate 40, such movement results in the endfaces 34 and 38 of the optical fibers 32, 36 moving out of alignment with one another, thus opening the optical switch assembly 10.

**[0019]** FIG. 3 illustrates the optical switch assembly 10 in the closed position. As shown, force is directed away from the flex plate 40 in the direction A in the general vicinity of the trench 42, while forces are directed toward the flex plate 40 at its ends in the direction B. Through this arrangement of forces, the flex plate 40 tends to move the endfaces 34, 38 into proper alignment with each other, thereby closing the optical switch assembly 10.

**[0020]** As noted above, the trench 42 of the flex plate 40 is preferably isotropically etched. The trench 42 should preferably extend across the flex plate as shown in FIG. 4. It is preferred that the trench 42 has a smooth sidewall 43 to prevent any localized mechanical stress during the previously described flexing operations. It is to be understood that a suitable flex plate 40 includes an area, such as the trench 42 or any other similar structure, that has a different flexing capability or profile relative to the remaining portion of the flex plate 40.

**[0021]** FIG. 5 illustrates another aspect of the invention with reference to an optical switch assembly 100 which includes a first optical array 111 and a second optical array 121 positioned on a flex plate 140. The optical arrays 111, 121 are each mounted on spheres 139. Specifically, the first optical array 111 has a second surface 118 including one or more grooves 119 and the second optical array 121 has a second surface 128 having at least one groove 129. The flex plate 140 also has a plurality of grooves 141 on an upper surface thereof which mate with the grooves 119, 129. Spheres 139 seat within the grooves 141. As shown, the groove 129 is elongated relative to the grooves 141. Elongation of the groove 129 relative to its mating groove 141 allows the second optical array 121 to move in a direction C relative to the first optical array 111 during assembly, thus allowing adjustment of the gap between the endfaces 34, 38. Once the gap has been properly adjusted, the optical arrays 111, 121 are then immobilized relative to the flex plate 140. Preferably, the grooves 119, 129, 141 are anisotropically wet etched with potassium hydroxide or other suitable etchant material.

**[0022]** FIG. 6 illustrates another optical switch assembly 200, which includes the first optical array 12, the second optical array 22, and a flex plate 240. The flex plate 240 is a silicon-on-insulator (SOI) wafer which includes a pair of silicon layers 244, 248 sandwiching an insulator layer 246. The trench 42 is isotropically etched in the silicon layer 244 by etchant materials. The insulator layer 246 is preferably formed of a material which is resistant to the etchant materials used to etch the silicon layer 244.

The proper depth of the trench 42 is obtained by the position of the insulator layer 246, which suppresses etching of the trench 42.

[0023] With reference to FIGS. 7-9, another aspect of the invention is shown with reference to an optical switch 300 which includes a first optical array 211, a second optical array 221, a third optical array 231, a fourth optical array 261, a fifth optical array 271, and a flex plate 280. The first optical array 211 includes a chip 212, which has a first surface 214, a second surface 218, and a face 220. The second optical array 221 includes a chip 222, which has a first surface 224, a second surface 228, and a face 230. The third optical array 231 is positioned between the first and second optical arrays 211, 221, and includes a chip 232, which has a first surface 234, a second surface 238, and a pair of faces 237, 239. The face 237 mates with the face 220 of the first optical array 211, while the face 239 mates with the face 230 of the second optical array 221.

[0024] The first surfaces 214, 224, 234 each include at least one groove 216, 226, 236, respectively. An optical fiber 250 is positioned within the groove 216, an optical fiber 252 is positioned within the groove 226, and an optical fiber 254 is positioned within the groove 236. There is an interface 256 that extends between the face 237 of the chip 232 and the endface of its respective optical fiber 254 and the face 220 of the chip 212 and the endface of its respective optical fiber 250. Further, there is an interface 258 that extends between the face 239 of the chip 232 and the endface of

optical fiber 254 and the face 230 of the chip 222 and the endface of its respective optical fiber 252.

[0025] The fourth and fifth optical arrays 261 and 271 are on-edge optical arrays which collect light which has been reflected from the interfaces 256, 258. The fourth optical array 261 includes a chip 262, having a groove 264, and an optical fiber 266. The fifth optical array 271 includes a chip 272, having a groove 274, and an optical fiber 276. The fourth optical array 261 is positioned transverse to the alignment of the first, second and third optical arrays 211, 221, 231 and generally in the vicinity of the interface 256. The fifth optical array 271 is positioned transverse to the alignment of the first, second and third optical arrays 211, 221, 231 and generally in the vicinity of the interface 258.

[0026] The flex plate 280 includes a pair of etched trenches 282, 284. Each of the trenches 282, 284 is positioned beneath one of the interfaces 256, 258. With specific reference to FIG. 8, by directing a force in the direction A away from the flex plate 280 in the general vicinity of the third optical array 232, and by concurrently directing forces in the direction B toward the flex plate 280 at its edges, light which is input from a light source 286 is transmitted along the optical fibers 250, 254, and 252 to an output destination 288. If instead, as shown in FIG. 9, a force is directed in the direction B toward the flex plate 280 in the general vicinity of the third optical array 232, and forces are directed away from the flex plate 280 in the direction A at the

plate's 280 edges, the interfaces 256, 258 are misaligned to such an extent as to suppress light from being transmitted through the optical fibers 250, 254, and 252. Instead, light from the light source 286 may be sent through the optical fiber 250, reflected at the gap between the optical fiber 250 and the optical fiber 254, collected by the optical fiber 266, and transmitted to the output destination 288. In addition, light from a second light source 290 concurrently may be sent through the optical fiber 252, reflected at the gap between the optical fiber 252 and the optical fiber 254, collected by the optical fiber 276, and transmitted to a second output destination 292.

**[0027]** The optical switch assembly 300 is particularly useful for ring networks in which a switch must be continuously connected and disconnected from a data ring. A conventional ring network 350, shown in FIG. 10, includes a plurality of nodes 302 in communication with each other. FIG. 11 illustrates the inclusion of the optical switch assembly 300 in a data ring 400. Light from a light source 286 which is within the data ring 400 is transmitted to the optical switch 300 and reflected into the optical array 262 and sent to the output destination 288, which in this instance is one of the nodes 302. Further, light from a light source 290 which is within the data ring 400 also is transmitted to the optical switch 300, reflected into the optical array 272 and sent to the output destination 292, which in this instance is the same node 302.

**[0028]** With reference to FIGS. 12-13, next will be described a method of assembling an optical switch assembly in accordance with an embodiment of the

invention. The optical switch assembly shown in FIGS. 12-13 includes a first optical array 312 and a second optical array 322. The first optical array 312 includes a first surface 314 and a second surface 318. At least one groove 316 is located in the first surface 314, and at least one pit 317 is also located in the first surface 314. The second optical array 322 includes a first surface 324 and a second surface 328. At least one groove 326 is located in the first surface 324, and at least one pit 327 is further located in the first surface 324. The second surfaces 318, 328 are to be mounted on the flex plate 40.

[0029] A tool 330, having at least a pair of pits 334 in a first surface 332 is used to align the first optical array 312 relative to the second optical array 322. Spheres 336 are positioned within the pits 334 and the optical arrays 312, 322 are moved so that the spheres 336 concurrently fit within the pits 317, 327, thereby adjusting the position of the first optical array 312 with respect to the second optical array 322. The spheres 336 may be adhered to the pits 334 with an adhesive material 338. Once proper position has been obtained, the optical arrays 312, 322 are immobilized relative to the flex plate 40 and the tool 330 is removed.

[0030] While the invention has been described in detail in connection with the preferred embodiments known at the time, it should be readily understood that the invention is not limited to such disclosed embodiments. Rather, the invention can be modified to incorporate any number of variations, alterations, substitutions or

equivalent arrangements not heretofore described, but which are commensurate with the spirit and scope of the invention. For example, although the flex plate 40 has been shown to have a semicircularly-shaped trench 42, it should be understood that the trench may be any suitable shape capable of localizing the flexing potential of the flex plate 40. Also, instead of a trench 42, the area with a different flex profile from the remainder of the flex plate 40 may be formed with a hinge or biasing member or other suitable mechanism. Further, while the tool 330 has been illustrated to show alignment of one optical array with another, it is to be understood that the tool 330 may be modified to align three optical arrays, such as optical arrays 211, 221, 231 shown in FIG. 7, and the remaining optical arrays 261 and 271 may be separately aligned. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

**[0031]** What is claimed as new and desired to be protected by Letters Patent of the United States is:

1. An optical switch, comprising:
  - first and second optical arrays separated by an interface; and
  - a support structure upon which said optical arrays are mounted, said support structure including an area which has a flexing profile that differs from the remainder of said support structure, wherein the operation of force on said support structure serves to optically couple and de-couple said optical arrays.
2. The optical switch of claim 1, wherein said first optical array includes a first chip and a first optical fiber, and said second optical array includes a second chip and a second optical fiber, said first and second chips being mounted on said support structure.
3. The optical switch of claim 2, wherein each said chip includes a groove, said optical fibers being mounted within said grooves.
4. The optical switch of claim 1, wherein said support structure comprises a flex plate and said area comprises a trench.
5. The optical switch of claim 4, wherein said optical arrays are mounted on said flex plate such that said trench is positioned beneath said interface.

6. The optical switch of claim 4, wherein said trench has a smooth sidewall.
7. The optical switch of claim 4, further comprising:
  - one or more grooves located on said chips;
  - a plurality of grooves located on said flex plate, wherein said optical arrays are mounted on said flex plate such that said grooves on said chips mate with respective said grooves on said flex plate; and
  - a plurality of spheres positionable within said grooves on said chips and said flex plate.
8. The optical switch of claim 7, wherein one said groove on said chips is elongated relative to the other said grooves, said elongated groove allowing movement of one of said optical arrays relative to the other of said optical arrays prior to mounting of said optical arrays on said flex plate.
9. The optical switch of claim 4, wherein said flex plate includes an etch stop layer.
10. An optical switch, comprising:
  - first, second and third optical arrays, wherein said third optical array is interposed between said first and second optical arrays, said first and third optical arrays are separated by a first interface, and said second and third optical arrays

are separated by a second interface;

a support structure upon which said first, second and third optical arrays are mounted, said support structure including a pair of areas which each have a flexing profile that differs from the remainder of said support structure; and fourth and fifth optical arrays, wherein said fourth optical array is positioned transverse to said first and third optical arrays in the vicinity of said first interface and said fifth optical array is positioned transverse to said second and third optical arrays in the vicinity of said second interface.

11. The optical switch of claim 10, wherein said optical arrays each include an optical fiber mounted on a chip.

12. The optical switch of claim 11, wherein each said chip has a groove, said optical fibers being mounted in said grooves.

13. The optical switch of claim 10, wherein said support structure comprises a flex plate and said areas each comprise a trench.

14. The optical switch of claim 13, wherein said flex plate includes an etch stop layer.

15. The optical switch of claim 13, wherein said first, second and third optical arrays are mounted on said flex plate such that one said trench is

positioned beneath said first interface and the other said trench is positioned beneath said second interface.

16. The optical switch of claim 15, wherein said optical arrays are capable of selective optical coupling with one another.

17. The optical switch of claim 16, wherein forces directed in certain directions and at certain locations of said flex plate optically couple said first, second and third optical arrays together.

18. The optical switch of claim 16, wherein forces directed in certain directions and at certain locations of said flex plate optically couple said first and fourth optical arrays together.

19. The optical switch of claim 16, wherein forces directed in certain directions and at certain locations of said flex plate optically couple said second and fifth optical arrays together.

20. A method for assembling an optical switch, comprising:  
aligning at least a first optical array and a second optical array relative to one another with an alignment tool;  
positioning said at least first and second optical arrays on a support structure;  
immobilizing said at least first and second optical arrays relative to said

support structure; and

removing said tool from said at least first and second optical arrays.

21. The method of claim 20, wherein said aligning comprises:

mating at least a first groove on said tool with at least a first groove on  
said first optical array;

mating at least a second groove on said tool with at least a second groove  
on said second optical array; and

positioning a sphere within said mated first grooves and positioning a  
sphere within said mated second grooves.

22. The method of claim 20, wherein said positioning comprises locating on  
said support structure said at least first and second optical arrays with an  
interface therebetween.

23. The method of claim 22, wherein said locating is such that upon certain  
forces directed in certain directions and at certain locations of said support  
structure said interface is lessened and said at least first and second optical arrays  
are optically coupled.

24. The method of claim 20, wherein said immobilizing comprises adhering  
said at least first and second optical arrays to said support structure.

25. The method of claim 20, wherein said aligning comprises aligning said first and second optical arrays relative to a third optical array, said third optical array being interposed between said first and second optical arrays.
26. The method of claim 25, wherein said positioning comprises locating on said support structure said first, second and third optical arrays with a first interface between said first and third optical arrays and a second interface between said second and third optical arrays.
27. The method of claim 26, wherein said locating is such that upon certain forces directed in certain directions and at certain locations of said support structure, said first and second interfaces are lessened and said at least first and second optical arrays are optically coupled with said third optical array.
28. The method of claim 25, wherein said immobilizing comprises adhering said first, second and third optical arrays to said support structure.

ABSTRACT

[0032] An optical switch and method for assembling are described. Optical arrays are mounted on a flex plate with an interface between them. The direction of certain forces on the flex plate allows coupling/decoupling of the optical arrays. The flex plate includes an area which exhibits a different flex profile than the remainder of the flex plate and that is located beneath the optical arrays interface. Flexing of the flex plate optically couples the optical arrays. A tool with grooves is used to align the optical arrays relative to each other. The tool uses grooves and spheres to mate with the optical arrays in such a way as to provide an appropriate interface between the optical arrays.

FIG. 1

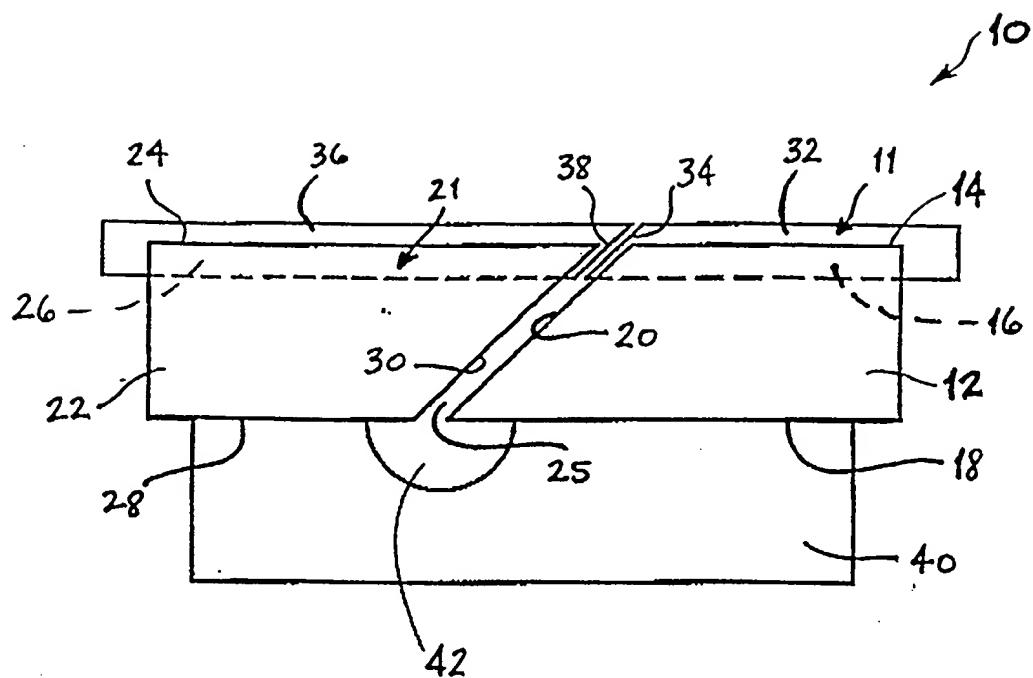


FIG. 2

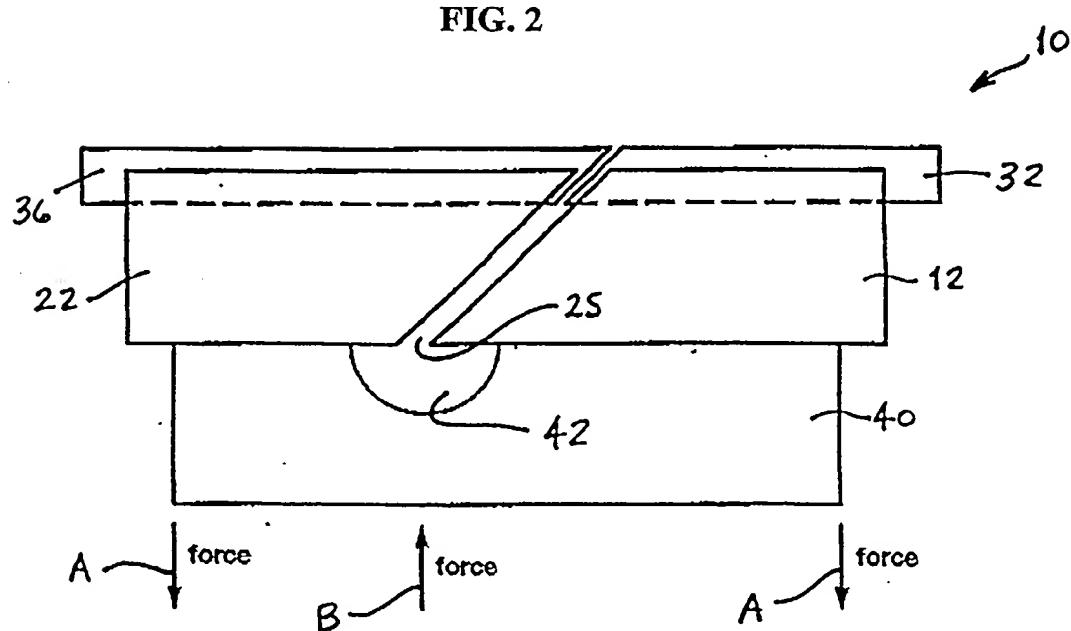


FIG. 3

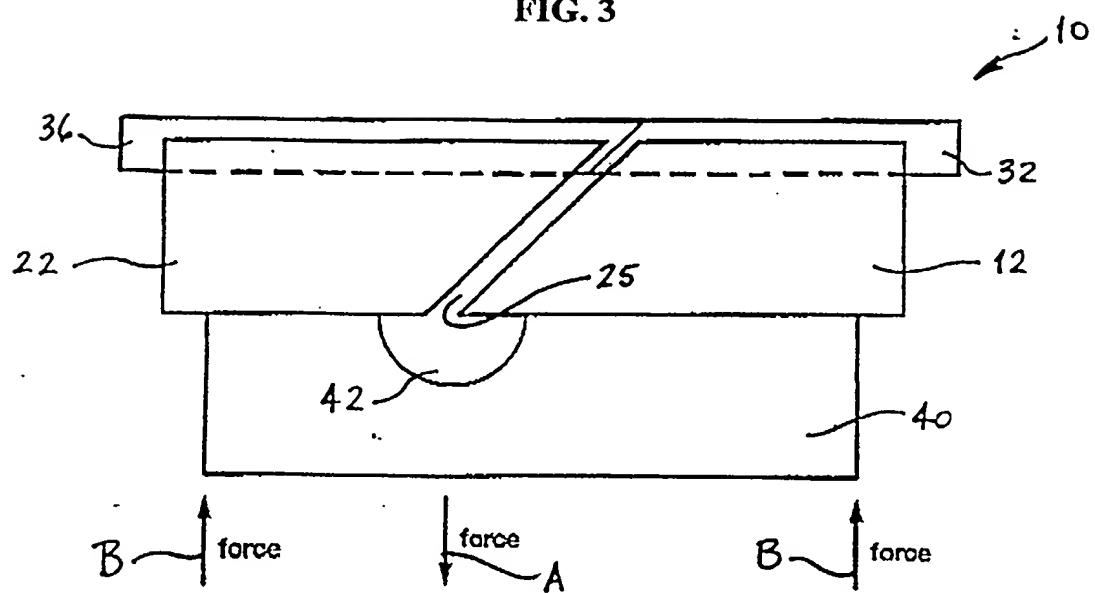


FIG. 4

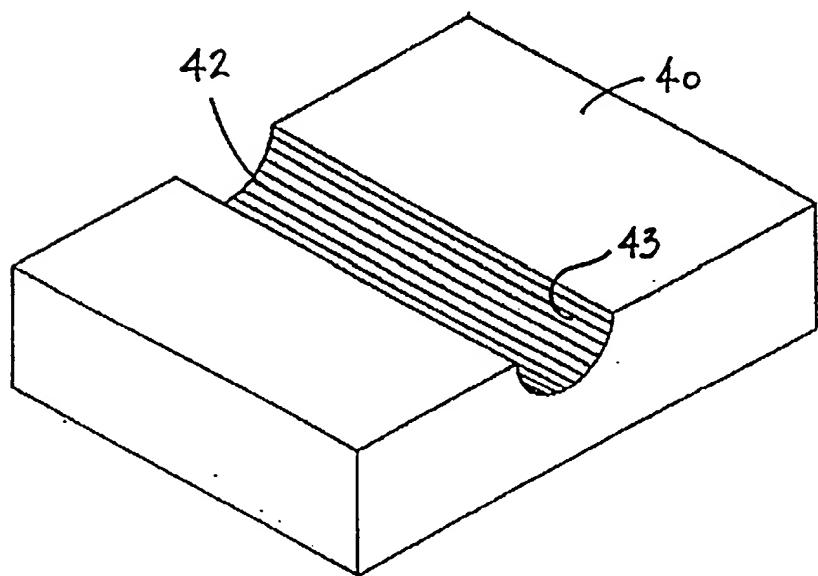


FIG. 5

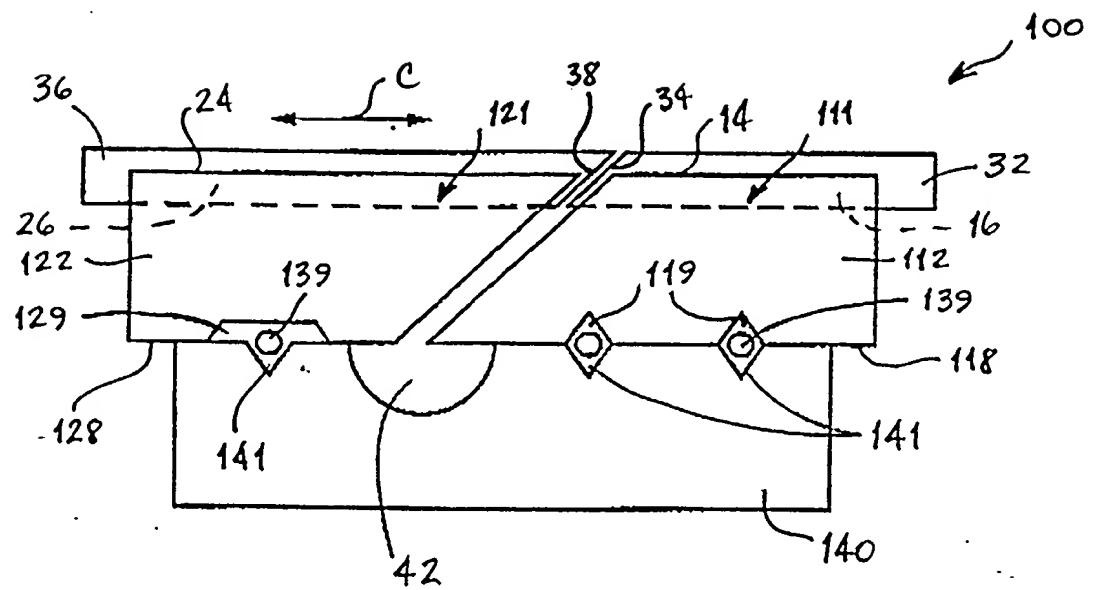


FIG. 6

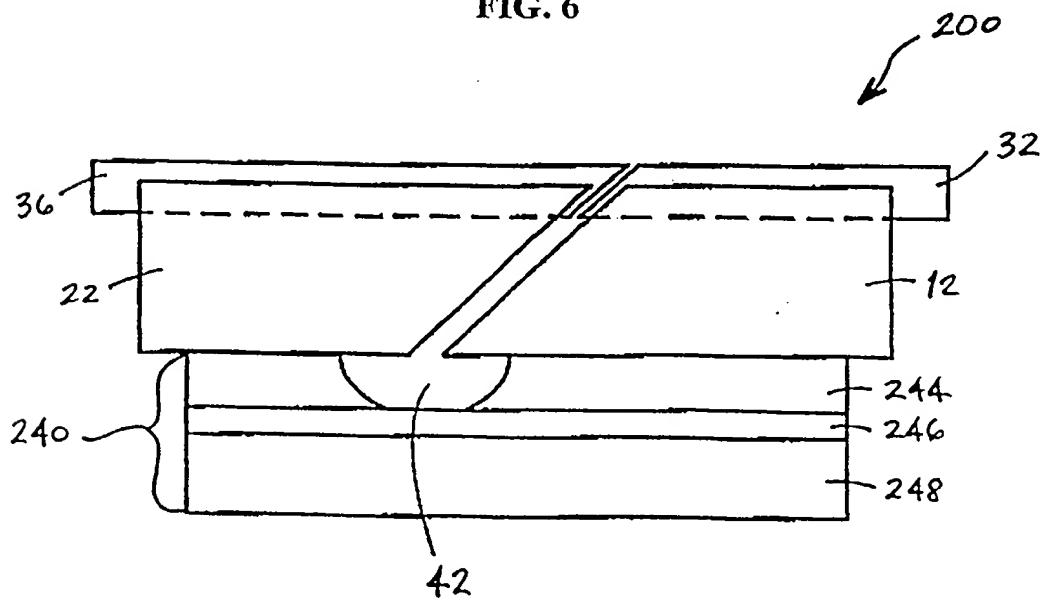


FIG. 7

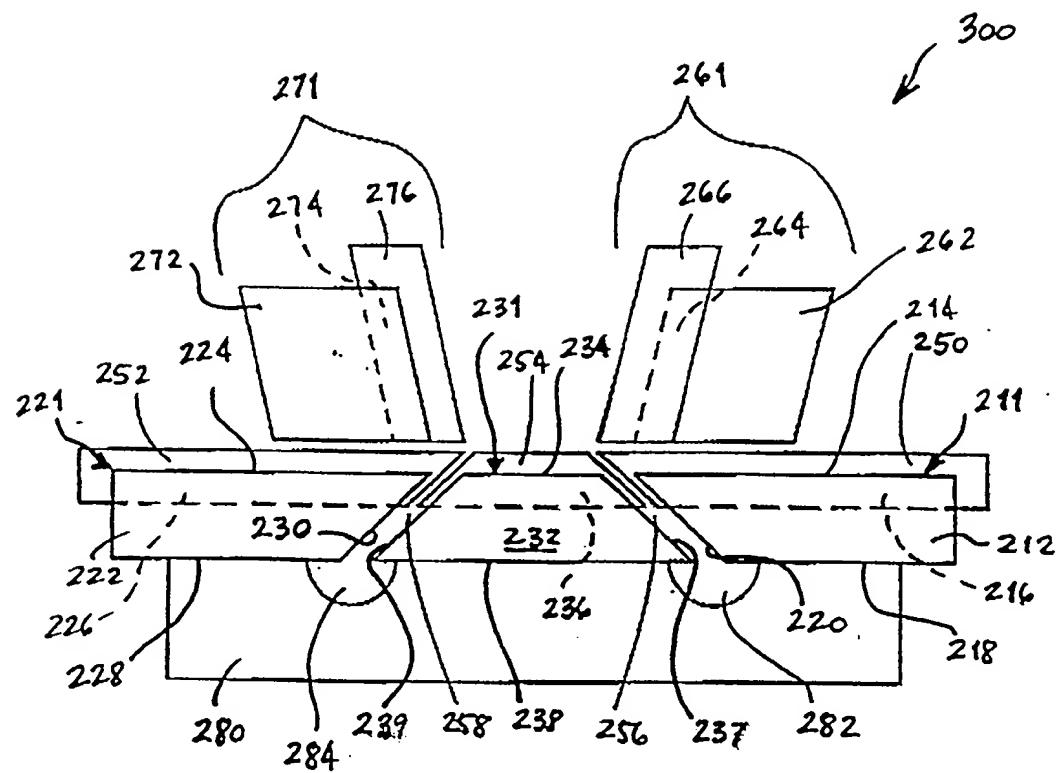


FIG. 8

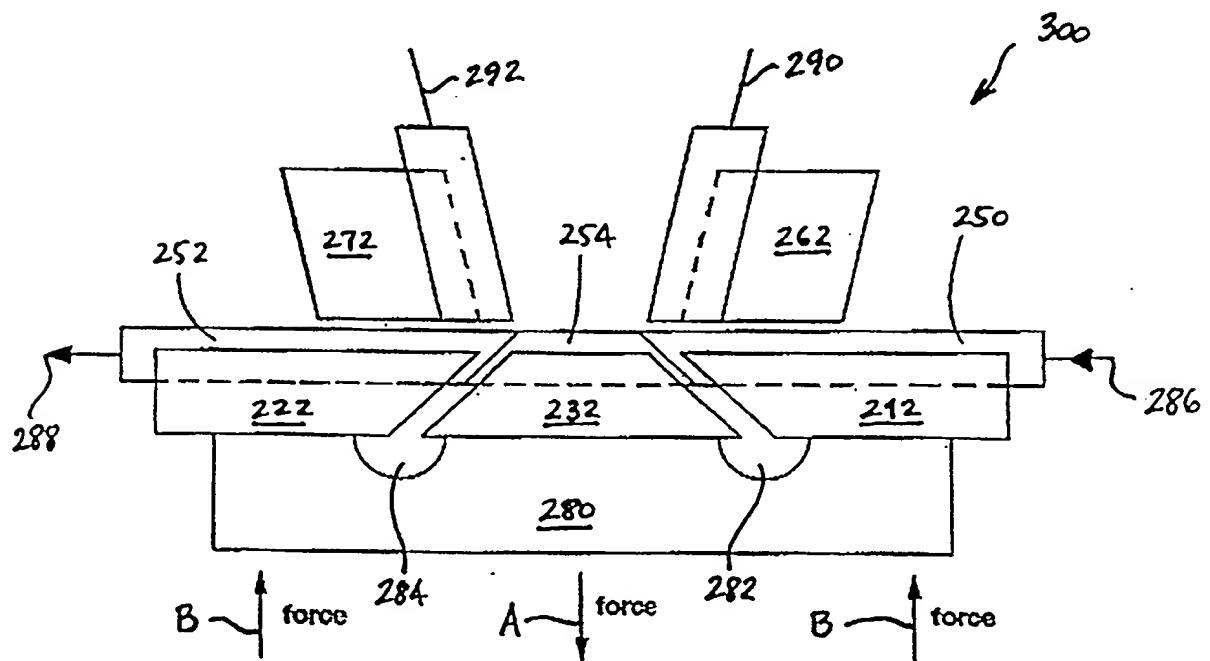


FIG. 9

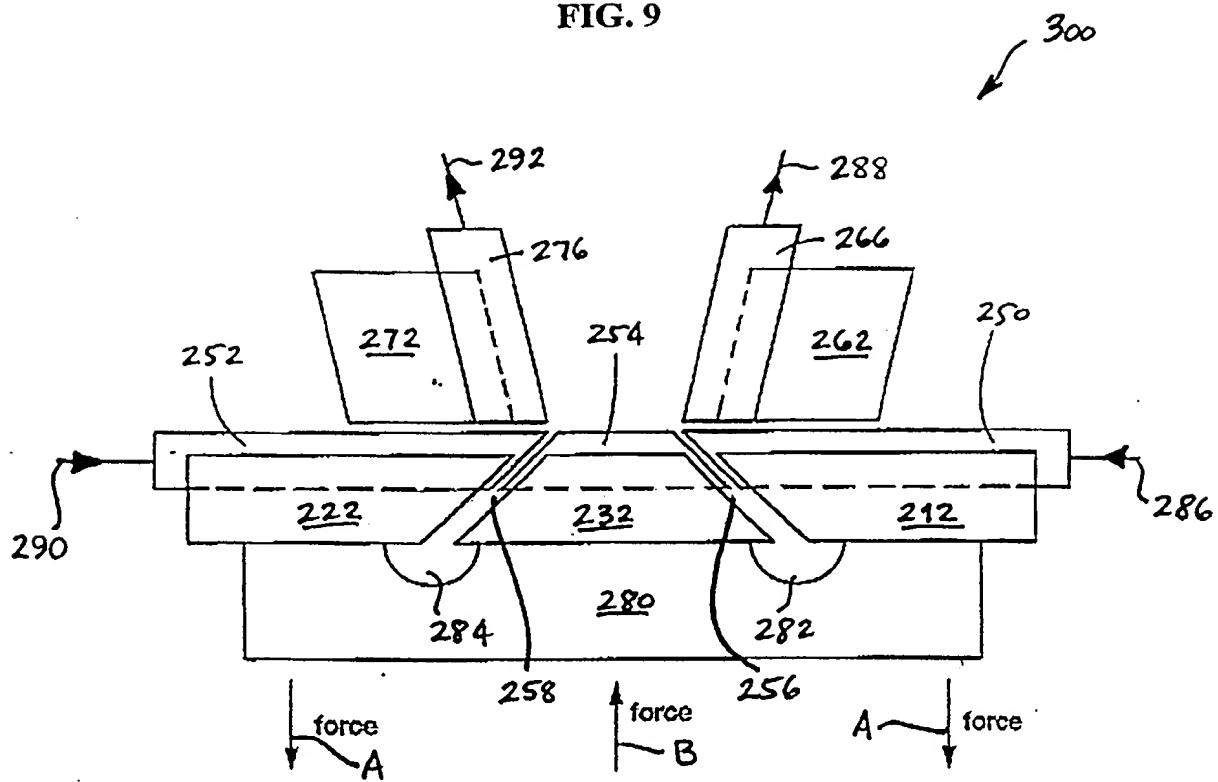


FIG. 10

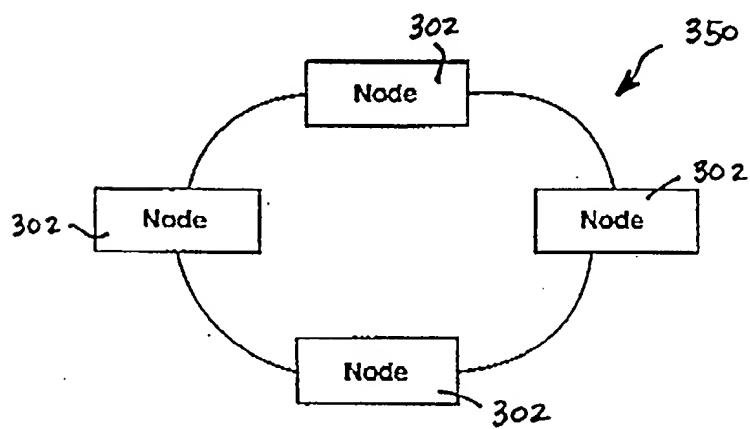


FIG. 11

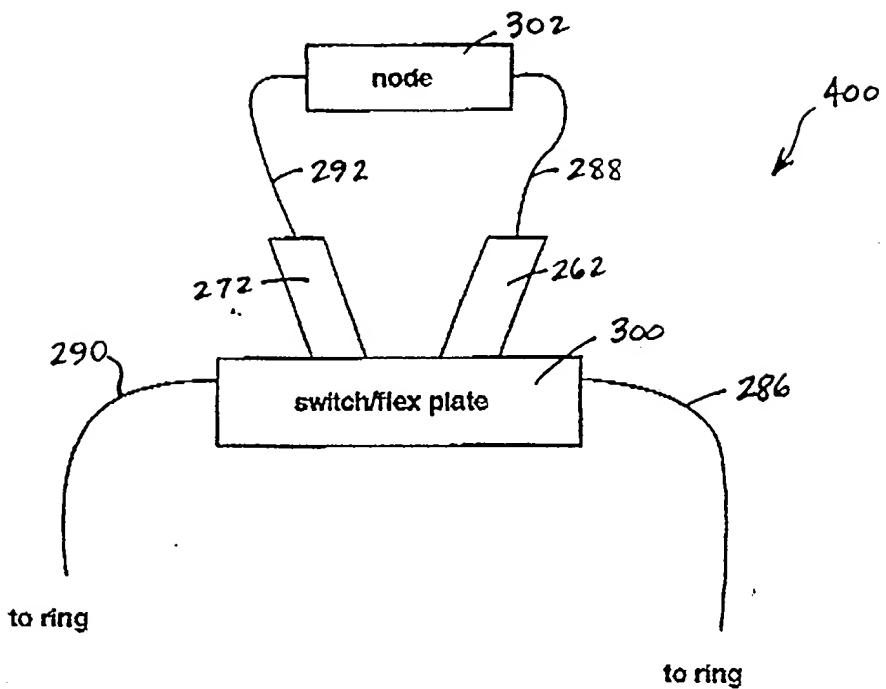
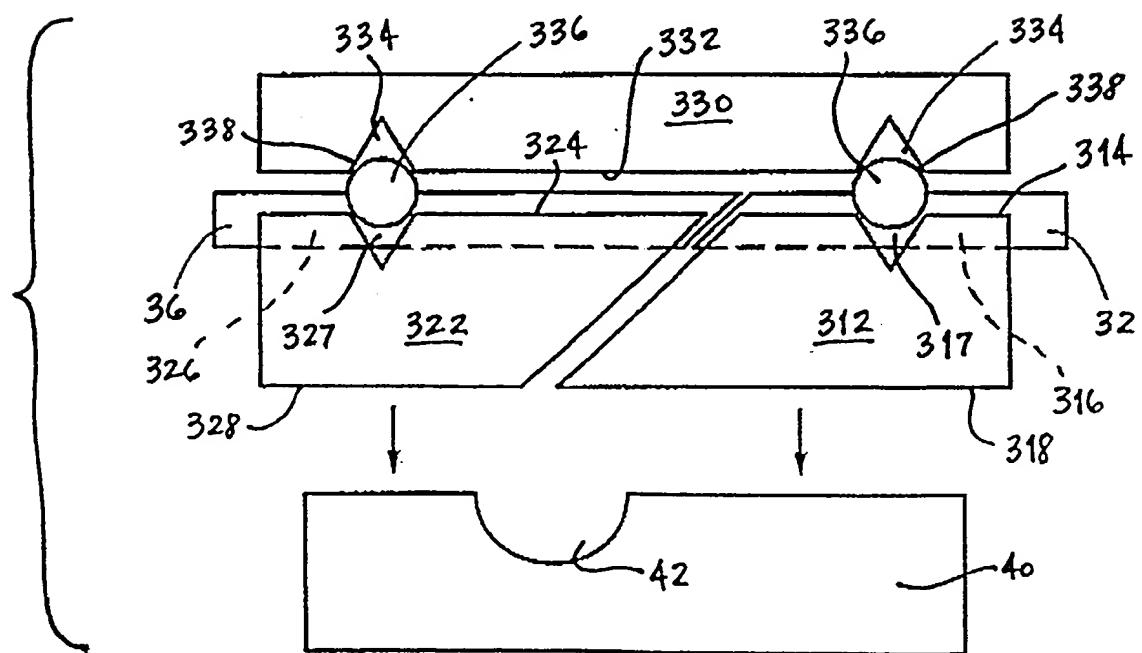
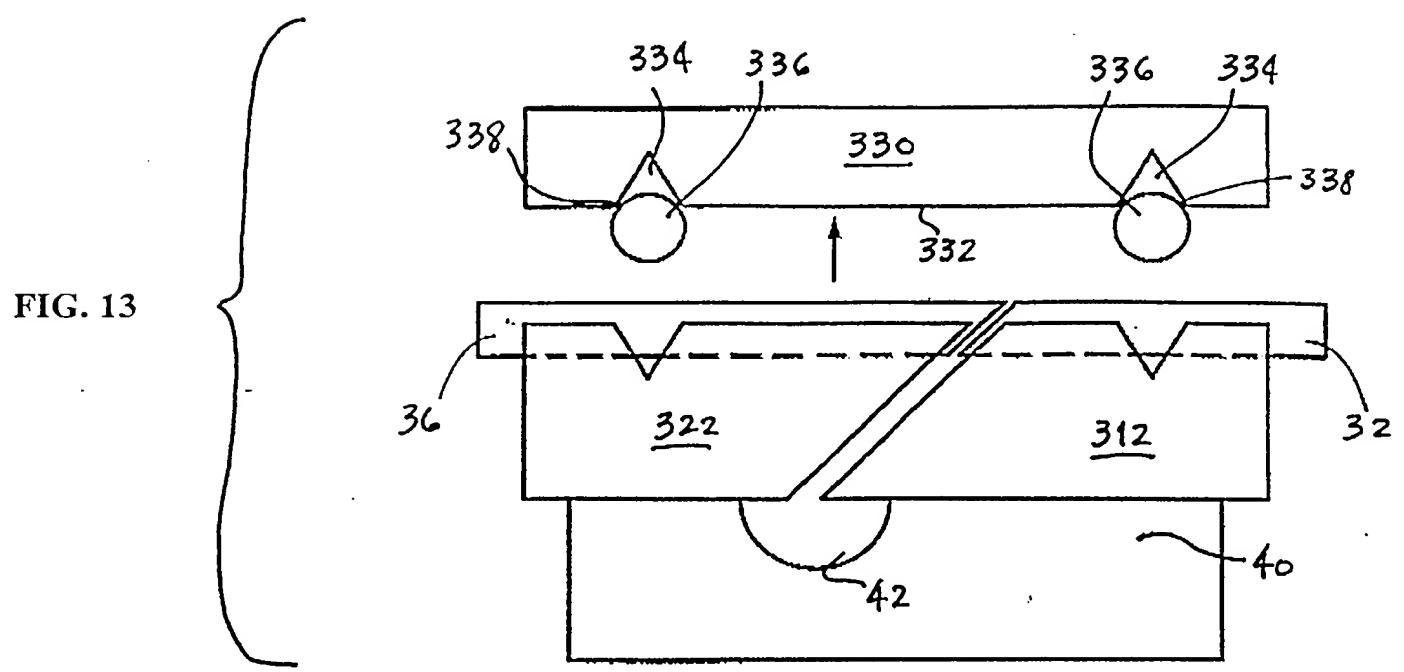


FIG. 12





## OPTICAL WAVEGUIDE SWITCH

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### Related Applications

**[0001]** The present application is a continuation-in-part of U.S. Patent Application 09/835,106 entitled "Optical waveguide switch", filed April 13, 2001, which in turn claims the benefit of priority of both U.S. Provisional Patent Application 60/197,154 entitled "Fiber Array Switch Having Micromachined Front Face," filed April 13, 2000 and U.S. Provisional Patent Application 60/201,347 entitled "Optical Fiber Array Switches and Alternative Embodiments," filed May 2, 2000. The present application is also a continuation-in-part of U.S. Patent Application, 09/833,282 entitled "Fiber Optic Array Switch", filed April 12, 2001, which claims the benefit of priority of U.S. Provisional Patent Application 60/197,120, filed on April 14, 2000. The disclosures of the above-captioned patent applications are specifically incorporated by reference as though reproduced in their entirety herein.

### Field of the Invention

**[0002]** The present invention relates generally to optical waveguide switches, and in particular to an array (MxN) optical switch.

### Background of the Invention

**[0003]** The increasing demand for high-speed voice and data communications has led to an increased reliance on optical communications, particularly optical fiber communications. The use of optical signals as a vehicle to carry channeled information at high speeds is preferred in many instances to carrying channeled information at other electromagnetic wavelengths/frequencies in media such as microwave transmission lines, co-axial cable lines and twisted pair transmission lines. Advantages of optical

media are, among others, high-channel capacity (bandwidth), greater immunity to electromagnetic interference, and lower propagation loss. In fact, it is common for high-speed optical communication systems to have signal rates in the range of approximately several Giga bits per second (Gbit/sec) to approximately several tens of Gbit/sec.

[0004] One way of carrying information in an optical communication system, for example an optical network, is via an array of optical fibers. Ultimately, the optical fiber array may be coupled to another array of waveguides, such as another optical fiber array, or a waveguide array of an optoelectronic integrated circuit (OEIC). In order to assure the accuracy of the coupling of the fiber array to another waveguide array, it becomes important to accurately position each optical fiber in the array.

[0005] Optical switches serve a variety of applications in optical communication systems. Once such variety of optical switches are mechanical switches. Mechanical optical switches have been used in a variety of optical fiber routing applications to switch between particular optical signal pads to provide reliable optical transmission routes for carrying optical signals.

[0006] Many mechanical optical switch configurations which are commercially available are typically characterized as either optical-component-moving-type or fiber-moving-type switch configurations. Illustratively, optical-component-moving-type switches include configurations that employ movable optical element (e.g. mirrors or prisms) to selectively redirect signals from an end of a first optical fiber to an end from a second optical fiber wherein the optical fibers are arranged in a parallel manner with their ends adjacent one another. While beneficial optical-component-moving-type switches typically elaborate and often too expensive for large scale implementation.

[0007] Conventional fiber-moving-type switch configurations may provide multiple-port switching. However, these types of optical switches suffer from complexity, expense and chronically poor alignment which requires frequent and labor intensive adjustment. The relative complexity of conventional fiber-moving-type switches has resulted in prohibitive cost and relatively high alignment tolerances which ultimately impair the performance of the device.

[0008] Accordingly, what is needed is a relatively simple, inexpensive, mechanically stable optical switch configuration capable of providing multiple-port switching in a variety of optical applications.

### Summary of the Invention

[0009] The present invention provides an optical switch, comprising: a substrate having an upper surface; a first waveguide holding member disposed over the upper substrate surface; a second waveguide holding member disposed over the upper substrate surface and slidably movable relative to the first waveguide holding member to provide a switching function; and a movement guiding member disposed between the upper substrate surface and the second waveguide holding member for guiding the movement of the second waveguide holding member, the movement guiding member comprising at least one detent for positioning the second waveguide holding member at a selected location relative to the first waveguide holding member to selectively couple a waveguide of the second waveguide holding member to a waveguide of the first waveguide holding member.

[0010] The at least one detent may comprise a plurality of detents which define preferred locations of the second waveguide holding member. The preferred locations provide alignment between waveguides of the first waveguide holding member and waveguides of the second waveguide holding member. The movement guiding member may comprise a positioning member, such as a sphere or a rod, for engagement with the detents. The movement guiding member may also comprise a plurality of registration elements between which the detents are located. The registration elements may comprise a plurality of rods or spheres that are adjacent to one another. The regions between the adjacent rods or spheres provide the detents.

### Brief Description of the Drawings

[0011] The foregoing summary and the following detailed description of the preferred embodiments of the present invention will be best understood when read in conjunction with the appended drawings, in which:

[0012] Figure 1 schematically illustrates a perspective view of an optical fiber switch according to an exemplary embodiment of the present invention;

[0013] Figure 2 schematically illustrates an exploded view of an optical switch according to an exemplary embodiment of the present invention;

[0014] Figure 3 schematically illustrates an exploded view of an optical switch according to an exemplary embodiment of the present invention;

[0015] Figure 4 schematically illustrates a top view of an optical switch according to yet another exemplary embodiment of the present invention;

[0016] Figure 5 schematically illustrates a top view of an optical switch according to yet another exemplary embodiment of the present invention;

[0017] Figures 6-9 schematically illustrate top views of substrates and waveguide holding members according to exemplary embodiments of the present invention;

[0018] Figure 10 schematically illustrates an exploded view of the switch of Figure 2, but having registration spheres disposed in one of the transverse grooves of the substrate which cooperate with a positioning sphere to facilitate passive alignment of optical fibers at multiple switch positions;

[0019] Figure 11 schematically illustrates a perspective view of a portion of a multiple-position passive alignment mechanism of the present invention in which registration elements are provided within a groove of the switch;

[0020] Figures 12 and 13 schematically illustrate a top view and a side elevational view, respectively, of an exemplary embodiment of a multiple-position passive alignment mechanism of the present invention which includes registration spheres that cooperate with two positioning spheres to facilitate passive alignment of optical fibers at multiple switch positions;

[0021] Figures 14 and 15 schematically illustrate a top view and a side elevational view, respectively, of an exemplary embodiment of a multiple-position passive alignment mechanism of the present invention that includes pits for retaining registration spheres that cooperate with two positioning spheres to facilitate passive alignment of optical fibers at multiple switch positions;

[0022] Figure 16 schematically illustrates a top view of an exemplary embodiment of a multiple-position passive alignment mechanism of the present invention which

includes registration spheres disposed in two rows that cooperate with a positioning sphere to facilitate passive alignment of optical fibers at multiple switch positions;

[0023] Figure 17 schematically illustrates a top view of an exemplary embodiment of a multiple-position passive alignment mechanism of the present invention which includes a rod and a row of registration spheres that cooperate with a positioning sphere to facilitate passive alignment of optical fibers at multiple switch positions;

[0024] Figure 18 schematically illustrates a top view of a multiple-position passive alignment mechanism of an exemplary embodiment of the present invention which includes a row of registration spheres that cooperate with a positioning rod to facilitate passive alignment of optical fibers at multiple switch positions;

[0025] Figure 19 schematically illustrates a top view of a multiple-position passive alignment mechanism of an exemplary embodiment of the present invention which includes registration spheres disposed in two rows that cooperate with a positioning rod to facilitate passive alignment of optical fibers at multiple switch positions;

[0026] Figure 20 schematically illustrates an exploded view of an exemplary embodiment of a switch of the present invention which includes registration rods that cooperate with a positioning rod to facilitate passive alignment of optical fibers at multiple switch positions;

[0027] Figure 21 schematically illustrates a top view of the registration rods of Figure 20;

[0028] Figure 22 schematically illustrates a top view of an exemplary embodiment of a multiple-position passive alignment mechanism of the present invention which includes a row of registration rods that cooperate with a positioning sphere to facilitate passive alignment of optical fibers at multiple switch positions;

[0029] Figure 23 schematically illustrates a side elevational view of an exemplary embodiment of a multiple-position passive alignment mechanism of the present invention which includes detents that cooperate with a positioning sphere to facilitate passive alignment of optical fibers at multiple switch positions;

[0030] Figure 24 schematically illustrates an exploded view of an exemplary embodiment of a switch of the present invention which includes detents that cooperate with positioning spheres to facilitate passive alignment of optical fibers at multiple switch positions;

[0031] Figure 25 schematically illustrates an exploded view of an exemplary embodiment of a switch of the present invention which includes detents that cooperate with a positioning rod to facilitate passive alignment of optical fibers at multiple switch positions;

[0032] Figure 26 schematically illustrates a side elevational view of an exemplary embodiment of a multiple-position passive alignment mechanism of the present invention which includes detents that cooperate with a positioning protrusion to facilitate passive alignment of optical fibers at multiple switch positions;

[0033] Figure 27 schematically illustrates a side elevational view of an exemplary embodiment of a multiple-position passive alignment mechanism of a switch of the present invention which includes a row of registration spheres that cooperate with a positioning protrusion to facilitate passive alignment of optical fibers at multiple switch positions;

[0034] Figure 28 schematically illustrates a side elevational view of the exemplary embodiment of Figure 1, but having a spring to bias the first waveguide holding member towards the substrate; and

[0035] Figure 29 schematically illustrates an exploded view of a fiber array switch for use with a multiple-position passive alignment mechanism of the present invention.

#### Defined Terms

[0036] 1. As used herein, the term "on" may be directly on. Alternatively "on" may mean "over."

[0037] 2. As used herein, "longitudinal" means parallel to the optic axis of a waveguide (x-direction herein); "transverse" means perpendicular to the optic axis of a waveguide (y-direction herein).

[0038] 3. As used herein, "movement guiding member" means a device or structure which constrains movement along a selected path, such as a linear or arcuate path.

**Detailed Description of the Invention**

[0039] According to an exemplary embodiment of the present invention, an optical switch includes a first waveguide holding member and a second waveguide holding member disposed on a substrate. The first waveguide holding member moves relative to the second waveguide holding member. A movement guiding member guides the motion of the first waveguide holding member.

[0040] Advantageously, the first waveguide holding member moves transversely relative to the second waveguide holding member. The traverse motion enables selective coupling between a waveguide in the first waveguide holding member and a waveguide in the second waveguide holding member. Through this transverse motion of the second waveguide holding member, an optical switching action may be implemented.

[0041] Figure 1 shows an optical switch 100 according to an illustrative embodiment of the present invention. A first waveguide holding member 101 and a second waveguide holding member 102 are disposed over a substrate 103. Optical waveguides 105 and 106 are disposed in the first waveguide holding member 101 and the second waveguide holding member 102, respectively. The waveguides 105 and 106 within the first and second waveguide holding members are selectively optically coupled to one another. To this end, a gap spacing 104 between the first waveguide holding member 101 and the second waveguide holding member 102 may be set so that efficient optical coupling is achieved between selected waveguides in the first waveguide holding member 101 and the second waveguide holding member 102.

[0042] After the gap spacing 104 has been set via longitudinal motion (x-direction) of the second waveguide holding member 102 relative to the first waveguide holding member 101, transverse (y-direction) motion may be carried out to selectively couple/decouple optical waveguide(s) in the first waveguide holding member 101 to an optical waveguide(s) in the second waveguide holding member 102. Accordingly, by virtue of the transverse motion of the first waveguide holding member 101 relative to

the second waveguide holding member 102 the coupling/decoupling of waveguides may be used to achieve optical switching between selected waveguides.

**[0043]** Illustratively, the motion of the first waveguide holding member 101 and the second waveguide holding member 102 may be through the use of known mechanical actuators. These include, but are not limited to, electromagnetic, piezoelectric, microelectro-mechanical system (MEMs), and hydraulic devices.

**[0044]** Illustratively, waveguides 105 and 106 are optical fibers. However, they may be planar waveguides as well. The waveguides 105 and 106 may be disposed on the lower surfaces of the first and second waveguide holding members 101 and 102, respectively. This substantially avoids alignment problems due to variations in thicknesses of first and second waveguide holding members 101 and 102, respectively. Moreover, this placement of waveguides 105 and 106 substantially avoids front-side and back-side alignment errors. However, the optical waveguides may be located on the top surfaces of or within first and second waveguide holding members 101 and 102.

**[0045]** In the illustrative embodiment shown in Fig. 1, a movement guiding member (not shown) may be disposed so that the first waveguide holding member 101 moves transversely. Moreover, a similar movement guiding member may be disposed so that the second waveguide holding member 102 moves longitudinally. The longitudinal motion of the second waveguide holding member 102 allows adjustment of the gap spacing 104. For purposes of illustration and not limitation, after the gap spacing 104 has been set, the second waveguide holding member 102 may be secured in position by use of a suitable adhesive. For example, a suitable epoxy may be used to secure the second waveguide holding member 102 in position. Moreover, the second waveguide holding member 102 may be adhered to the substrate 103 by thermo-compression bonding with aluminum. The gap spacing may be in the range of 1  $\mu\text{m}$  to 15  $\mu\text{m}$ , for example. In addition, as illustrated in Fig. 28, a spring 120 may be provided above the first and second waveguide holding members 101, 102 to press the first waveguide holding member 101 towards the substrate 103. The spring 120 may be attached to the top of the second waveguide holding member 102 via a spring attachment 122, which may be an epoxy, for example. It is also of interest to note that the second waveguide holding member 102 may be located so that the gap spacing is set without longitudinal

motion. This may be achieved through use of alignment fiducials or other suitable devices.

[0046] In this illustrative embodiment, the second waveguide holding member 102 may also be capable of transverse (y-direction) motion. This may be accomplished using a suitably disposed movement guiding member to achieve transverse motion. As such, the switching capabilities of the optical switch 100 may be achieved by movement of one or both of the first and second waveguide holding members 101 and 102, respectively.

[0047] Turning to Fig. 2, an exploded view of an optical switch 200 according to an exemplary embodiment of the present invention is shown. A substrate 201 illustratively includes longitudinal grooves 203 and transverse grooves 202. The longitudinal grooves 203 and transverse grooves 202 are adapted to receive positioning members 204. The positioning members 204 are illustratively microspheres and may be other suitable friction-reducing elements that can translate within the grooves 202, 203, such as sliding or rolling elements. Selected positioning members 204 are disposed between the longitudinal grooves 203 of the substrate 201 and pits 207 in second waveguide holding member 206. Additional selected positioning members 204 are positioned between the transverse grooves 202 of the substrate 201 and pits 208 in first waveguide holding member 205. As can be readily appreciated the longitudinal and transverse grooves 202, 203 of the substrate 201 and the pits 208, 207 in the first and second waveguide holding members 205, 206, respectively are on opposing surfaces thereof.

[0048] Illustratively, transverse motion of the first waveguide holding member 205 is achieved by motion of the positioning members 204 in grooves 202. The positioning members 204 associated with the first waveguide holding member 205 are constrained relative to the first waveguide holding member 205 by pits 208 in the first waveguide holding member 205. Likewise, the positioning members 204 associated with the second waveguide holding member 206 are constrained relative to the first waveguide holding member 205 in pits 207 in the second waveguide holding member 206. Longitudinal motion of second waveguide holding member 206 is achieved through the motion of the positioning members 204 in the longitudinal grooves 203 of the substrate 201.

[0049] The longitudinal motion may be used to adjust gap spacing 209 between the first waveguide holding member 205 and the second waveguide holding member 206.

Transverse motion of the first waveguide holding member 205 may be used to achieve switching between waveguides 210 and 211. To this end, switching is achieved by selectively coupling/decoupling waveguides 211 disposed in first waveguide holding member 205 with waveguides 210 disposed in second waveguide holding member 206. Finally, it is of interest to note that waveguides 210 and 211 may be disposed on the lower surfaces of the first and second waveguide holding members 205 and 206, respectively. They may be held in v-grooves (not shown), for example. Moreover, the waveguides 210 and 211 may be disposed on the top surfaces of the waveguide holding members 205 and 206, respectively. Finally, waveguides 210 and 211 may be disposed within waveguide holding members 205 and 206, thereby being integral parts thereof.

[0050] Figure 3 shows an optical switch 300 according to another illustrative embodiment of the present invention. A substrate 301 has transverse grooves 302 and longitudinal grooves 303. Positioning members 304 are disposed between transverse grooves 302 and pits 305 in first waveguide holding member 306. The positioning members 304 are constrained in pits 305 and move along longitudinal grooves 302, which enables transverse motion of first waveguide holding member 306 in a manner similar to that described in connection with the illustrative embodiment of Fig. 2.

[0051] Positioning members 307 are disposed between longitudinal grooves 303 in substrate 301 and grooves 308 disposed in second waveguide holding member 309. Positioning members 307 are illustratively cylindrical-shaped rod elements which enable the longitudinal motion (x-direction) of first waveguide holding member 306. Illustratively, positioning members 307 may be sections of optical fiber or micromachined rods. Moreover, positioning members 304, 307 may be glass, metal or ceramic. Similar to the illustrative embodiment of Figs. 1 and 2 the longitudinal motion of second waveguide holding member 309 enables the adjustment of the gap spacing 310 between the first waveguide holding member 306 and the second waveguide holding member 309 to facilitate coupling of optical fibers 311 and 312.

[0052] In the illustrative embodiments of Figs. 2 and 3, the grooves 202, 203, 302, 303 and 308 may be illustratively v-shaped grooves. The pits 207, 208 and 305 are illustratively inverted pyramidal-shaped pits. The grooves and pits may be formed by illustrative techniques described below. Finally, in the illustrative embodiments of Figs.

2 and 3, the first waveguide holding members 205, 306 and the second waveguide holding member 206 each include four pits which constrain positioning members 204 and 304. As can be readily appreciated, three pits are desirable for stability and motion constraint. Other numbers of pits and positioning members may be used in keeping with the present invention. Finally, the grooves 202, 203, 302, 303, 308, pits 207, 208, 305, and positioning members 204, 304 may be coated with a coating material to reduce wear and/or friction, such as silicon nitride, for example. The coating material may be selected with regard to the sliding and frictional properties and may be selected to have a low coefficient of friction, low wear, and long life so that the fiber alignment is not negatively affected by material wear.

**[0053]** The inverted pyramidal pits and grooves may be formed by anisotropic wet etching of a monocrystalline material, such as single crystal silicon. Illustratively, the monocrystalline material may be selectively etched according to known techniques. The surfaces of the inverted pyramidal pits are disposed along the well-defined crystallographic planes of the monocrystalline material. One such known technique for anisotropic etching of monocrystalline material may be found in U.S. Pat. No. 4,210,923 to North, et al., the disclosure of which is specifically incorporated herein by reference. Of course, other known etching techniques (wet or dry) may be used to form the pits and grooves. Moreover, other materials may be used for the substrate and first and second waveguide holding members. These include, but are not limited to, glass, quartz, metal or plastic. The grooves and pits may be formed therein by known techniques, such as molding.

**[0054]** In the illustrative embodiments of the present invention, a movement guiding member may comprise a positioning member disposed between a pit and a groove. The pits may be located in the waveguide holding member or in the substrate depending on application. Moreover, a movement guiding member may comprise a positioning member disposed between two grooves. Again, the grooves may be located in the substrate and in the waveguide holding member. Again, this is merely illustrative of the movement guiding members of the exemplary embodiments of the present invention, and other movement guiding members may be used in carrying out the invention.

[0055] Figure 4 shows an optical switch 400 according to an illustrative embodiment of the present invention. A substrate 401 has transverse v-grooves 402 disposed therein. The substrate 401 further includes longitudinal v-grooves 403. A first waveguide holding member 404 includes first waveguides 405. The waveguides 405 may be disposed on top of the first waveguide holding member 404; on the bottom of first waveguide holding member 404; or within the first waveguide holding member 404. A second waveguide holding member 406 includes second waveguides 407. The second waveguides 407 may be disposed on a top surface of the second waveguide holding member 406; a bottom surface of second waveguide holding member 406; or within the second waveguide holding member 406. Waveguides 405 and 407 are illustratively optical fibers. However, waveguides 405 and 407 may be planar waveguides. In the illustrative embodiment of Fig. 4, first positioning members 408 are disposed in pits 409 in the first waveguide holding member 404. Likewise, second positioning members 410 are disposed in pits 411 in the second waveguide holding member 406.

[0056] As described above, the pits 409 are illustratively inverted pyramidal pits. The first positioning members 408 are relatively contained within the pits 409 and cooperatively engage the longitudinal grooves 403. Illustratively, a movement guiding member may comprise a first positioning member 408 disposed between a pit 409 and a longitudinal groove 403. In the illustrative embodiment shown in Fig. 4, such a configuration provides for motion of the first waveguide holding member 404 in the  $\pm$  x-direction. As can be readily appreciated, motion in the  $\pm$  x-direction facilitates the longitudinal alignment of the first waveguides 405 relative to the second waveguides 407. Particularly, the constrained linear motion of the first waveguide holding member 404 in the longitudinal direction enables the proper selection of the gap spacing 412.

[0057] Illustratively, a movement guiding member may comprise a second positioning member 410 disposed between a pit 411 and a transverse groove 402 of second waveguide holding member 406. The second positioning members 410 are disposed in pits 411. Again, the second positioning members 410 are constrained in the pits 411, which are illustratively inverted pyramids. The second positioning members 410 are constrained by grooves 402 to move in the traverse direction. In the illustrative

embodiment shown in Fig. 4, this results in the transverse motion of the second waveguide holding member 406 in the  $\pm y$ -direction.

[0058] The transverse motion of waveguides 407 relative to waveguides 405 enables the selective coupling/ decoupling of waveguides. This facilitates the switching of a signal from one waveguide to another. For example, an optical signal may be traversing waveguide 413 of the first waveguide holding member 404. This waveguide may be coupled to waveguide 414 disposed in second waveguide holding member 406. As can be readily appreciated, movement of the second waveguide holding member 406 in either the  $+y$ -direction or the  $-y$ -direction may uncouple waveguide 413 from waveguide 414. Movement in the  $+y$ -direction, for example of a predetermined distance may enable coupling of the optical signal traversing waveguide 413 into waveguide 415. As such, coupling of the optical signal is "switched" from waveguide 414 to waveguide 415.

[0059] In the exemplary embodiment, waveguides 405 and 407 each comprise a row of three waveguides. Of course, this is for purposes of illustration, and more or fewer waveguides may be used. Moreover, as can be readily appreciated, waveguides 405 of the first waveguide holding member 404 may be a linear array (a row) or a matrix of a suitable number of rows and columns of optical waveguides. Likewise, optical waveguides 407 of the second waveguide holding member 406 may also be a linear array (a row) or a matrix having a suitable number of rows and columns. Moreover, the pitch between the waveguides 405 may be the same or different than that of the waveguides 407. As such, sophisticated switching schemes may be realized through the transverse motion of the second waveguide holding member 406 relative to the first waveguide holding member 404.

[0060] Figure 5 shows an optical switch 500 according to another illustrative embodiment of the present invention. A substrate 501 has transverse grooves 502 disposed therein. The substrate 501 also includes longitudinal grooves 503. The transverse grooves 502 receive positioning members 504 which are disposed in pits 505 in the second waveguide holding member 506. In the present illustrative embodiment, movement guiding members may comprise a positioning member 504 disposed between pits 505 and transverse grooves 502.

[0061] The motion of the positioning members 504 in the transverse grooves 502 enables the transverse motion (y-direction) of the second waveguide holding member 506 relative to the first waveguide holding member 507. The transverse motion enables the selective coupling/decoupling of optical waveguides 508, 509 and 510 to waveguides 511, 512 and 513, respectively. Transverse motion of the second waveguide holding member 506 would change this coupling, enabling a switching action.

[0062] In the illustrative embodiment of Fig. 5, positioning members 514 are disposed in pits 515 in the second waveguide holding member 507. As can be readily appreciated, the engagement of the positioning members 514 within the longitudinal grooves 503 in the substrate 501 enables longitudinal movement (x-direction) of the second waveguide holding member 507. According to the illustrative embodiment of Fig. 5, the second waveguide holding member 507 may have an endface 516 which is polished. The gap spacing 517 may be accurately determined by elements 518 which are illustratively ball lenses or microspheres disposed in grooves 519 in the first waveguide holding member 506. The gap spacing 517 is illustratively in the range of 1  $\mu\text{m}$  to 15  $\mu\text{m}$ .

[0063] Figures 6-9 are illustrative embodiments of substrate and waveguide holding members according to the present invention. These embodiments are intended to be illustrative of different combinations of grooves and pits which will allow the relative transverse motion of the first and second waveguide holding members for optical switching. These exemplary embodiments also provide longitudinal motion to adjust a gap spacing between the first and second waveguide holding members. These embodiments are intended to be illustrative, and in no way exhaustive of the combinations of the location of grooves and pits that can be used to carry out the invention of the present disclosure.

[0064] Figure 6 shows the elements of an optical switch 600 according to an illustrative embodiment of the present invention. A substrate 601 includes grooves 602 and pits 603. Again, the grooves 602 and pits 603 are fabricated by known techniques as described in detail above. The grooves 602 and pits 603 are adapted to receive positioning members (not shown) to such as those described in the connection with the illustrative embodiments above. A first waveguide holding member 604 includes grooves 605 having the positioning members (not shown) therein

which enable the transverse motion (y-direction) of the first waveguide holding member 604. The second waveguide holding member 606 has grooves 607 therein. The grooves 607 which are adapted to receive the positioning members (not shown) enable the longitudinal motion (x-direction) of the second waveguide holding member 606. Again, the transverse motion of the first waveguide holding member 604 relative to the second waveguide holding member 606 enables the switching operation of waveguides 608 and 609. The longitudinal motion of the second waveguide holding member 606 enables the optical coupling of the optical fibers 608 and 609 by adjusting the gap spacing therebetween. In the illustrative embodiment shown in Fig. 6, it may be useful to adhere the second waveguide holding member 606 to the substrate 601 after the gap spacing has been set.

[0065] Figure 7 shows another optical switch 700 according to yet another illustrative embodiment of the present invention. The substrate 701 has grooves 702 which cooperatively engage positioning members (not shown) enabling transverse motion of the first waveguide holding member 703. The positioning members are disposed in pits 704 in the first waveguide holding member 703. Longitudinal grooves 705 receive positioning members (not shown) which are disposed in pits 707 in the second waveguide holding member 706. This enables longitudinal movement of the second waveguide holding member 706.

[0066] As described in connection with the illustrative embodiments above, waveguides 708 and 709 are selectively coupled/decoupled with the transverse motion of the first waveguide holding member 703 relative to the second waveguide holding member 706. Moreover, the longitudinal motion of the second waveguide holding member 706 enables accurate gap spacing between the first waveguide holding member 703 and the second waveguide holding member 706, thereby enabling efficient coupling between the waveguides 708 and 709. After the gap spacing is adjusted, a suitable adhesive may be used to fix the position of the second waveguide holding member 706 and thereby set the gap spacing at the determined position.

[0067] Figure 8 shows an optical switch 800 according to yet another illustrative embodiment of the present invention. In the illustrative embodiment of Fig. 8, a substrate 801 has transverse grooves 802 which cooperatively engage positioning

members (not shown) which may be disposed in grooves 803 in the first waveguide holding member 804. As can be readily appreciated, the arrangement of the grooves 802 and 803 with the positioning member disposed therebetween enables the transverse motion of the first waveguide holding member 804. Pits 805 receive positioning members (not shown). These positioning members are disposed in grooves 806 in second waveguide holding member 807. Again, the longitudinal motion of the second waveguide member enables the coupling of waveguides 808 to waveguides 809 by setting the appropriate gap spacing between the waveguide holding members 804 and 807. The transverse motion of the first waveguide holding member 804 relative to the second waveguide holding member 807 results in the selective coupling/decoupling of waveguides 808 and 809 which enables the desired switching action.

[0068] Figure 9 shows an optical switch 900 according to yet another illustrative embodiment of the present invention. A substrate 901 has transverse grooves 902 which cooperatively engage positioning members (not shown). The positioning members also cooperatively engage grooves 903 disposed in the first waveguide holding member 904. As can be readily appreciated, the arrangement of grooves 902 and 903 with the positioning members disposed therebetween enables transverse motion of the first waveguide holding member 904. Second waveguide holding member 905 includes a groove 906 and a pit 907. The substrate 901 includes a groove 908 and pits 909. Positioning members (for example microspheres) may be positioned in pits 909 of the second waveguide holding member 905. These positioning members engage groove 906. A positioning member may also be disposed in pit 907. This positioning member may engage the groove 908 of the substrate 901. The combination of grooves 906, 908 and pits 907, 909 in the second waveguide holding member 905 and the substrate 901 enables the longitudinal motion of the second waveguide holding member 905.

[0069] In another aspect of the present invention, the movement guiding members may be provided with registration elements to create regions in which a positioning member preferentially seats. The preferential seating of the positioning member positions the first and second waveguide holding members relative to one another so that selected fibers in each holding member are in proper alignment. Thus, cooperation between the

registration elements and a positioning member creates preferred switching locations to provide a multiple-position, passive alignment mechanism for the switch.

[0070] For example, referring to Figs. 10 and 11, a modified version of the switch 200 of Fig. 2 is shown in which several registration elements 214, such as microspheres, are disposed within a transverse groove 202 of the substrate 201. Figure 11 illustrates an enlarged perspective view of a portion of the substrate 201 showing the transverse groove 202 with the registration elements 214 disposed therein.

[0071] The registration elements 214 are disposed adjacent one another within the transverse groove 202 to provide detents 216 between adjacent pairs of registration elements 214. As used herein, “adjacent” elements, such as registration elements 214, may be near one another or may be in contact with one another. The detents 216 provide regions along the transverse groove 202 in which a positioning member 204, such as a positioning sphere, can preferentially seat. As explained above, the positioning member 204 may be simultaneously retained within a pit 208 of the first waveguide holding member 205, so that the first waveguide holding member 205 tracks the motion of the retained positioning member 204. As illustrated in Fig. 11, as the positioning member 204 translates along the length of the transverse groove 202, the positioning member 204 follows a path, P, in which the preferred seating locations of the positioning member 204 are located within the detents 216 at the cusps of the path, P. The positioning member 204 and/or registration elements 214 may be coated with a wear-resistant material such as a suitable carbide or nitride material.

[0072] The registration elements 214 may be microspheres that may be dimensioned to fit within the transverse groove 202 so that the registration elements 214 lie below the plane of the upper surface 221 of the substrate 201. Such a configuration provides three point contact for the positioning member 204 in the detents 216. Two of the contact points are located on adjacent registration elements 214, and the third contact point is located on a sidewall 219 of the transverse groove 202. The location and number of detents 216 provided by the registration elements 214 may be arranged to correlate to the position and number of fibers 210, 211 in the waveguide holding members 205, 206, so that seating of the positioning member 204 within the detents 216 provides alignment between selected fibers 210, 211 of the first and second waveguide holding members

205, 206. For example, the spacing between detents 216 may be equal to the pitch of the fibers 210, 211. In further embodiments in accordance with the present invention, additional grooves, positioning members, and registration elements may be provided to enhance the kinematic stability or to enhance the tendency for a positioning member to reside at a particular location.

[0073] For example, referring to Figs. 12 and 13, an alternative configuration of an alignment mechanism 1200 having two positioning members 204 is illustrated. Figures 12 and 13 illustrate a portion of a substrate 1201 containing a transverse groove 1202, which may be the transverse groove 202 of switch 200, for example. The registration elements 1214 are provided adjacent one another within the transverse groove 1202 to provide detents 1216 between adjacent pairs of registration elements 1214. The registration elements 1214 are dimensioned relative to the transverse groove 1202 so that the registration elements 1214 protrude above the upper surface 1219 of the substrate 1201. The detents 1216 provide regions along the transverse groove 1202 in which positioning members 1204 can preferentially seat. Each positioning member 1204 may be simultaneously retained within a pit 1208 of a first waveguide holding member 1205, so that the first waveguide holding member 1205 tracks the motion of the retained positioning member 1204. The configuration of Figs. 12 and 13 provides two point contact between each positioning member 1204 and the corresponding registration elements 1214 against which each positioning member 1204 is seated. Thus, a total of four points of contact are provided which may produce enhanced kinematic stability of the alignment mechanism 1200.

[0074] Alternatively, a similar configuration of an alignment mechanism 1400 may be provided, as illustrated in Figs. 14 and 15, but with the registration elements 1414 disposed in individual pits 1402 rather than in a groove. The pits 1402 may be disposed in a row along the transverse direction. The pits 1402 may be provided in spaced apart relation so that the registration elements 1414 are not in contact, to provide detents 1416 having greater width along the transverse direction due to the spaced apart relation of the pits 1402. The increased width of the detents 1416 provides a greater distance, W, between the two points of contact between a positioning member 1404 and adjacent

registration elements 1414. The increased distance, W, may enhance the stability with which the positioning member 1404 is seated within a detent 1416.

[0075] In yet an additional configuration of an alignment mechanism in accordance with the present invention, an alignment mechanism 1600 may include two rows of registration elements 1614 disposed within transverse grooves 1602, as illustrated in Fig. 16. The registration elements 1614 may be provided adjacent one another within the transverse grooves 1602 to provide detents 1616 between adjacent pairs of registration elements 1614. The registration elements 1614 are dimensioned relative to the transverse groove 1602 so that the registration elements 1614 protrude above the upper surface of the substrate 1601. The grooves 1602 are disposed in spaced apart parallel relation a sufficient amount so that a positioning member 1604 may be in simultaneous contact with four registration elements 1614. Thus, four contact points are provided between the positioning member 1604 and the adjacent registration elements 1614. Similarly, in an alternative configuration, as illustrated in Fig. 17, one of the rows of registration elements may be replaced with a rod 1724. The rod 1724 may be disposed within a groove of the substrate 1701. In such a configuration a positioning member 1704 seated within a detent 1716 makes three point contact. One point of contact is made with the rod 1724, and one point of contact is made with each of the two registration elements 1714 that positioning member 1704 contacts, for a total of three points of contact.

[0076] In still further configurations of an alignment mechanism in accordance with the present invention, a rod-shaped positioning member, rather than spherical, may be provided. For example, referring to Figs. 18 and 19, alternative configurations of alignment mechanisms 1800, 1900 are illustrated. Figure 18 illustrates a portion of a substrate 1801 containing a transverse groove 1802, which may be the transverse groove 202 of switch 200, for example. Registration elements 1814 are provided adjacent one another within the transverse groove 1802 to provide detents 1816 between adjacent pairs of registration elements 1814. The registration elements 1814 may be dimensioned relative to the transverse groove 1802 so that the registration elements 1814 protrude above the upper surface of the substrate 1801. The detents 1816 provide regions along the transverse groove 1802 in which a rod-shaped positioning member 1804 can preferentially seat. The configuration of Fig. 18 provides two point contact between the

positioning member 1804 and the registration elements 1814 against which the positioning member 1804 is seated.

[0077] Similarly, Figure 19 illustrates an alignment mechanism 1900 which comprises a rod-shaped positioning element 1904. The registration mechanism 1900 includes two rows of registration elements 1914 disposed within the transverse grooves 1902. The transverse grooves 1902 may be the transverse grooves 202 of switch 200, for example. The registration elements 1914 may be provided adjacent one another within the transverse grooves 1902 to provide detents 1916 between adjacent pairs of registration elements 1914. The registration elements 1914 are dimensioned relative to the transverse groove 1902 so that the registration elements 1914 protrude above the upper surface of the substrate 1901. The grooves 1902 may be disposed in spaced apart parallel relation so that the rod-shaped positioning member 1904 may be in simultaneous contact with four registration elements 1914. Thus, four contact points are provided between the rod-shaped positioning member 1904 and the registration elements 1914 that the positioning member 1904 contacts.

[0078] In yet additional configurations of an alignment mechanism in accordance with the present invention, a rod-shaped registration element, rather than spherical, may be provided. For example, referring to Figs. 20-22, alternative configurations of alignment mechanisms are illustrated. Rod-shaped registration elements 2014 are provided adjacent one another in a row to provide detents 2016 between adjacent pairs of registration elements 2014. The row of rod-shaped registration elements 2014 may be provided along the transverse direction and may be disposed in a single groove or a series of grooves. The registration elements 2014 may be dimensioned so that the registration elements 2014 protrude above the upper surface of the substrate 2001. The detents 2016 provide regions along the transverse groove 2002 in which a rod-shaped positioning member 2004, as shown in Figs. 20 and 21, or a spherical positioning member 2005, as shown in Fig. 22, can preferentially seat. The configuration of Fig. 22 provides two point contact between the spherical positioning member 2005 and the registration elements 2014 against which the positioning member 2004 is seated. The configuration of Figs. 20 and 21 provides two line-contacts between the rod-shaped positioning member 2004

and the registration elements 2014 against which the rod-shaped positioning member 2004 is seated.

[0079] As an alternative to the above configurations of alignment mechanisms, the registration elements may be provided as depressions in the substrate. For example, referring to Fig. 23, a side elevational view is shown of a switch 2300 having registration elements 2316 in the form of depressions. The depressions may take the form of pits or grooves and may be created by isotropic wet etching, anisotropic etching, or a combination of etching techniques, for example. The registration elements 2316 are disposed in a row along the transverse direction to provide depressions in which a positioning member 2304, such as a positioning sphere, can preferentially seat. Alternatively, the positioning member 2304 may be a rod. The corners 2303 of the registration elements 2316 may be smoothed or rounded to facilitate movement of the positioning member 2304 into and out of the registration elements 2316. The positioning member 2304 may be retained within a pit 2308 of the first waveguide holding member 2305, so that the first waveguide holding member 2305 tracks the motion of the retained positioning member 2304. The location and number of registration elements 2316 may be arranged to correlate to the position and number of fibers in the waveguide holding members, so that seating of the positioning member 2304 within the detents 2316 provides alignment between fibers of the first and second waveguide holding members. The registration elements 2316 may be spaced apart from one another as illustrated in Fig. 23. Alternatively, registration elements 2416 may be depressions that are disposed next to one another as illustrated in Fig. 24. The registration elements 2416 may comprise a row of grooves in which a spherical positioning member 2404 or a rod-shaped positioning member 2504 is disposed, as illustrated in Figs. 24 and 25, respectively.

[0080] In certain uses, it may be desirable to provide a positioning member as an integral portion of a waveguide holding member, a substrate, or both. For example, referring to Figs. 26 and 27, side elevational views of a portion of a switch having an integral positioning member 2604 are illustrated. The positioning member 2604 may be a separate element attached to a waveguide holding member 2605 to provide a protrusion. Alternatively, the positioning member 2604 may be a protrusion that is

monolithic with the waveguide holding member 2605. The substrate 2601 may comprise registration elements provided in the form of a row of depressions 2602, which may include pits, grooves, or combinations of pits and grooves. The depressions 2602 and positioning member 2604 are dimensioned so that the positioning member 2604 may seat within the depressions 2602. Alternatively, microspheres 2614 may be provided within the depressions 2602 to provide detents 2616 in which the positioning member 2604 may seat.

**[0081]** The multiple-position, passive alignment mechanisms of the present invention, such as those described above, may also be used to provide preferred switching locations in other switch configurations such as a fiber array switch as illustrated in Fig. 29. The fiber array switch 2900 includes first and second arrays 2901, 2902 and grooves 2903, with positioning members 2906 sandwiched therebetween. The grooves 2903 may be provided with registration elements, such as those described above, to permit one array 2901 to be translationally moved relative to the other array 2902 into preferred switching locations defined by the registration elements. The positioning members 2906 may be provided as spheres, as illustrated in Fig. 29, or may be provided in other forms as disclosed herein.

**[0082]** The positioning members described above may comprise materials which include ceramics, such as silicon nitride, zirconia, alumina, spinel, aluminum nitride, and other ceramics. In addition, the positioning members may be made of glass or metals, such as steel or titanium. The rod-shaped components may be, for example, segments of optical fibers. Further, the positioning members and/or registration elements may be coated with a wear-resistant material such as a suitable carbide or nitride material.

**[0083]** From the foregoing description, particularly of the illustrative embodiments shown in Figs. 2-28, the following generalities may be realized. The grooves and pits may be collectively referred to as depressions. These depressions may be in the substrate and in the first and second waveguide holding members. A waveguide holding member usefully may have at least two depressions. The portion of the substrate opposed to the waveguide holding member (i.e. the portion of the substrate over which the waveguide holding member is disposed) may usefully include at least two depressions. Moreover,

at least three of the depressions may desirably be grooves. Finally, no two opposing depressions are pits. A similar analysis applies to the waveguide holding member disposed on the other portions of the substrate.

**[0084]** These and other advantages of the present invention will be apparent to those skilled in the art from the foregoing specification. Accordingly, it will be recognized by those skilled in the art that changes or modifications may be made to the above-described embodiments without departing from the broad inventive concepts of the invention. It should therefore be understood that this invention is not limited to the particular embodiments described herein, but is intended to include all changes and modifications that are within the scope and spirit of the invention as set forth in the claims.

## Claims

What is claimed is:

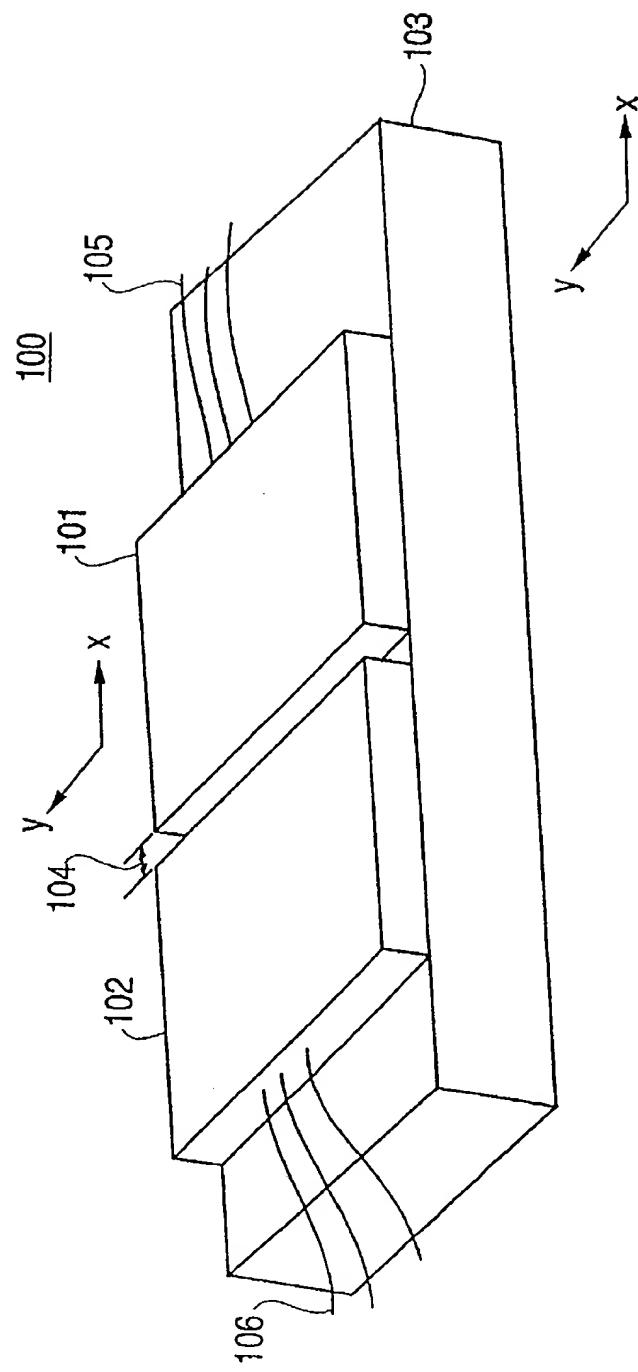
1. An optical switch, comprising:
  - a substrate having an upper surface;
  - a first waveguide holding member disposed over the upper substrate surface;
  - a second waveguide holding member disposed over the upper substrate surface and slidably movable relative to the first waveguide holding member to provide a switching function; and
  - a movement guiding member disposed between the upper substrate surface and the second waveguide holding member for guiding the movement of the second waveguide holding member, the movement guiding member comprising at least one detent for positioning the second waveguide holding member at a selected location relative to the first waveguide holding member to selectively couple a waveguide of the second waveguide holding member to a waveguide of the first waveguide holding member.
2. An optical switch as recited in claim 1, wherein the detent is dimensioned to receive a portion of the movement guiding member.
3. An optical switch as recited in claim 1, wherein the movement guiding member comprises a plurality of registration elements between which the detent is located.
4. An optical switch as recited in claim 3, wherein the at least one registration element comprises a plurality of adjacent spheres or rods.
5. An optical switch as recited in claim 3, wherein the movement guiding member comprises a transverse groove in which the at least one registration element is disposed.

6. An optical switch as recited in claim 1, wherein the movement guiding member comprises a transverse groove in which the detent is disposed.
7. An optical switch as recited in claim 1, wherein the movement guiding member comprises a positioning member for engagement with the detent.
8. An optical switch as recited in claim 7, wherein the positioning member is a monolithic part of the second waveguide holding member.
9. An optical switch as recited in claim 7, wherein the positioning member comprises a sphere disposed within a pit of the second waveguide holding member.
10. An optical switch as recited in claim 7, wherein the detent is positioned so that movement of the positioning member into registry with the detent selectively couples a waveguide of the second waveguide holding member to a waveguide of the first waveguide holding member.
11. An optical switch as recited in claim 1, wherein the second waveguide holding member comprises a plurality of fibers disposed in spaced apart relation at a pitch, and the at least one detent comprises a plurality of detents spaced apart from one another at the same pitch as the fibers.
12. An optical switch as recited in claim 1, wherein the movement guiding member guides the movement of the second waveguide holding member along a direction perpendicular to the optical axis of a fiber retained by the second waveguide holding member.
13. An optical switch as recited in claim 1, wherein the movement guiding member guides the movement of the second waveguide holding member parallel to the upper substrate surface.

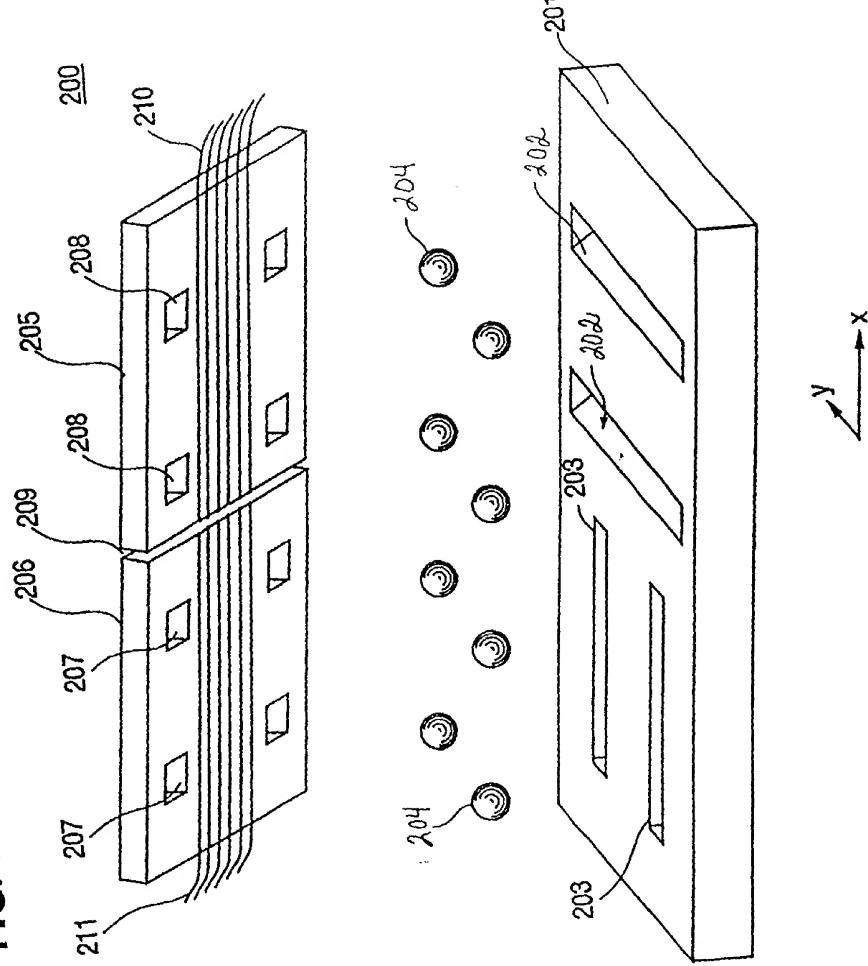
### **Abstract**

The present invention provides an optical switch. The switch includes a substrate and a first waveguide holding member. The switch also includes a second waveguide holding member disposed over the substrate and movable relative to the first waveguide holding member to provide a switching function. A movement guiding member is provided for guiding the movement of the second waveguide holding member. A registration element is disposed at the movement guiding member for positioning the second waveguide holding member at a selected location relative to the first waveguide holding member. The selected location is one that provides alignment between a selected waveguide of the first waveguide holding member and a selected waveguide of the second waveguide holding member.

**FIG. 1**



**FIG. 2**



**FIG. 3**

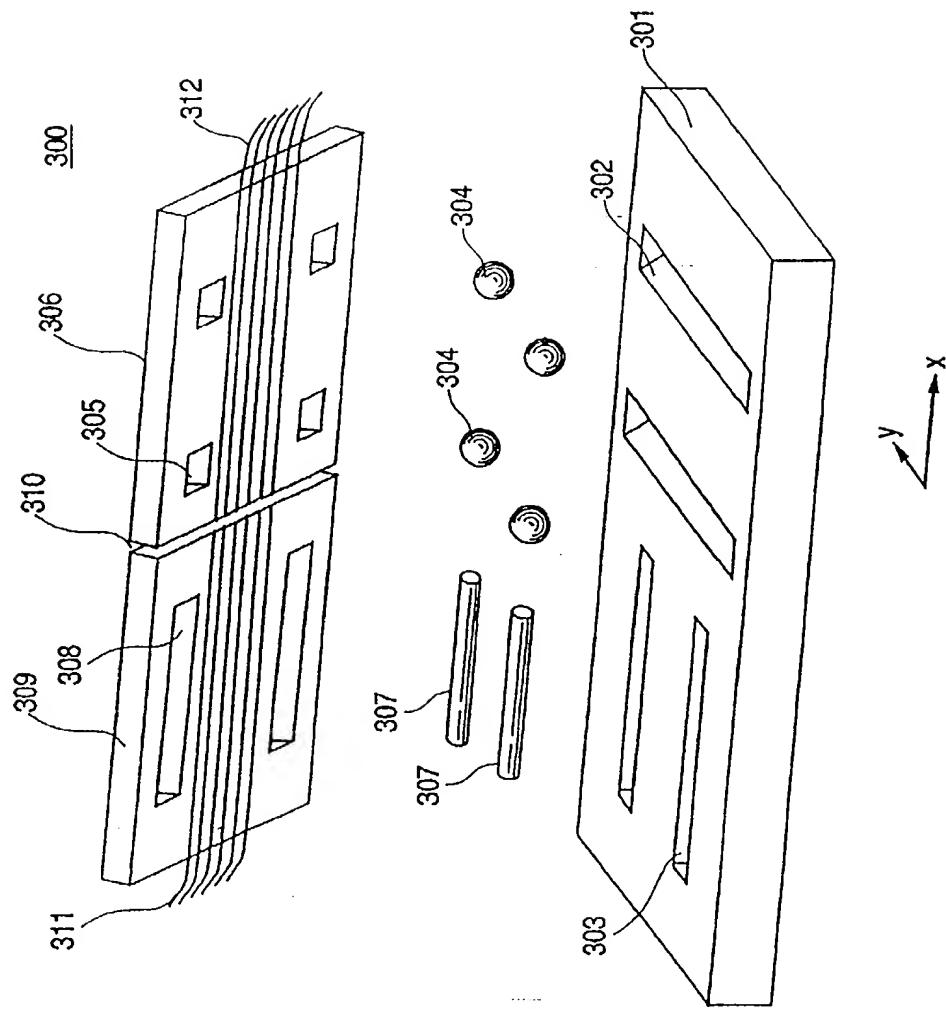


FIG. 4

400

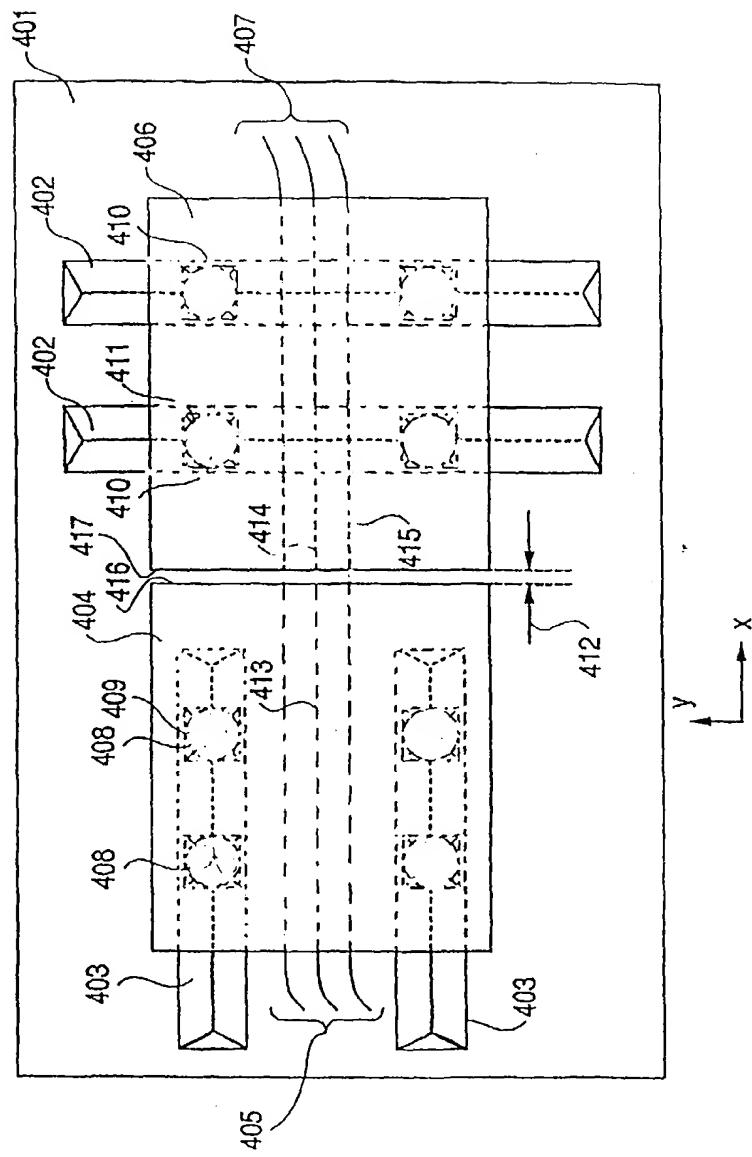
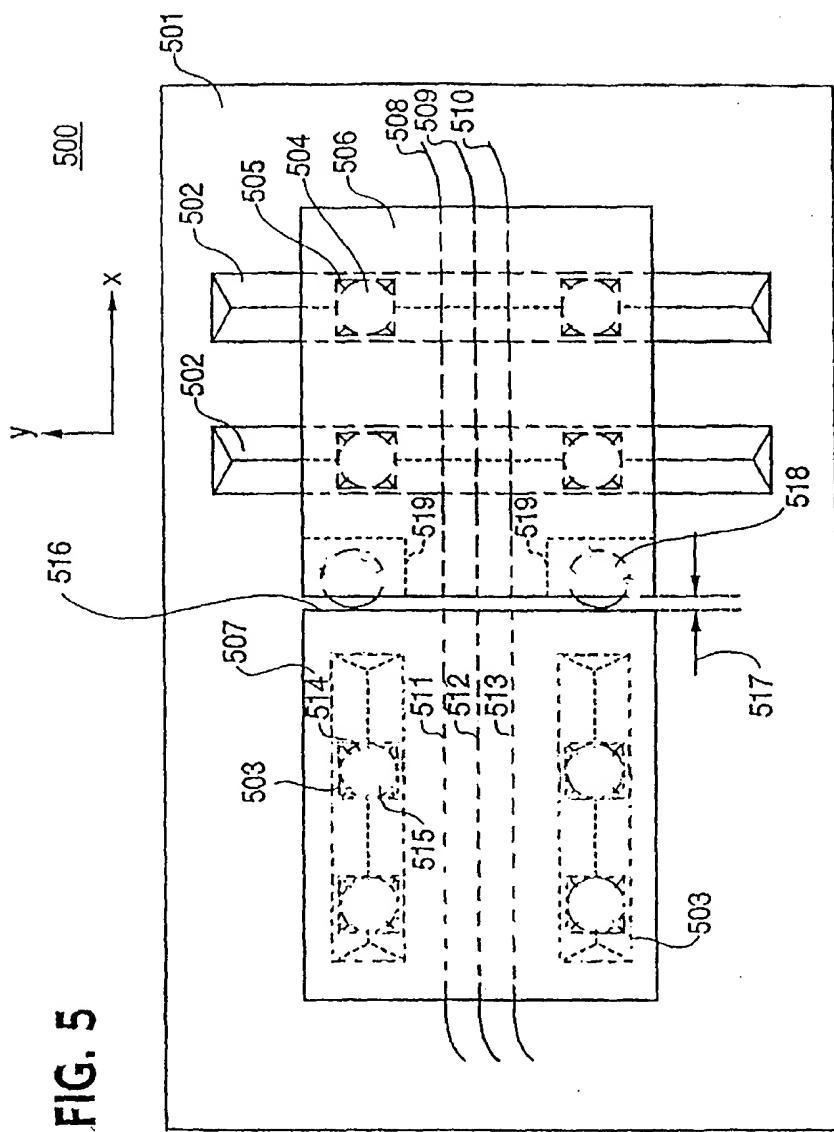
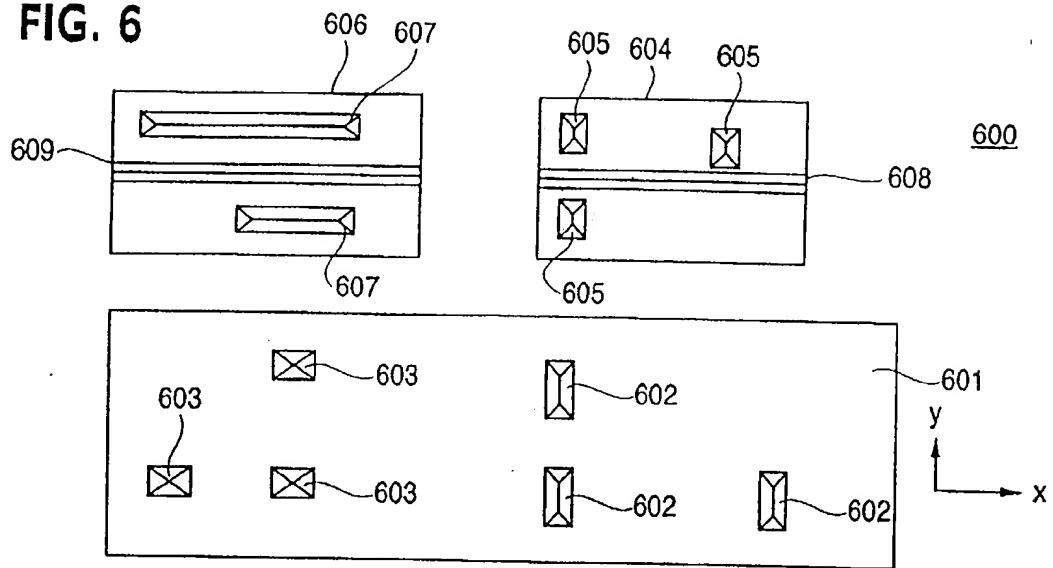


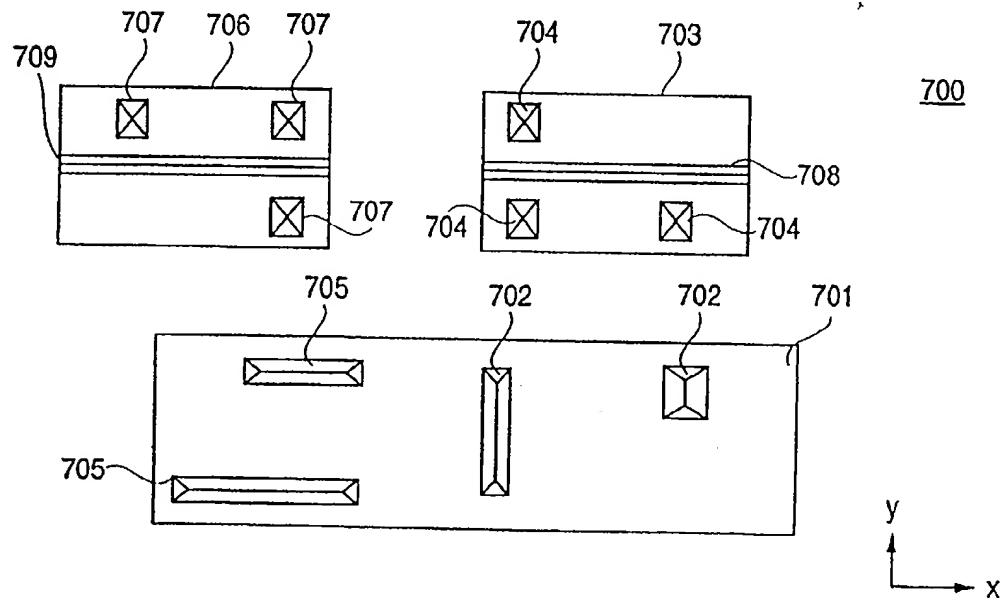
FIG. 5



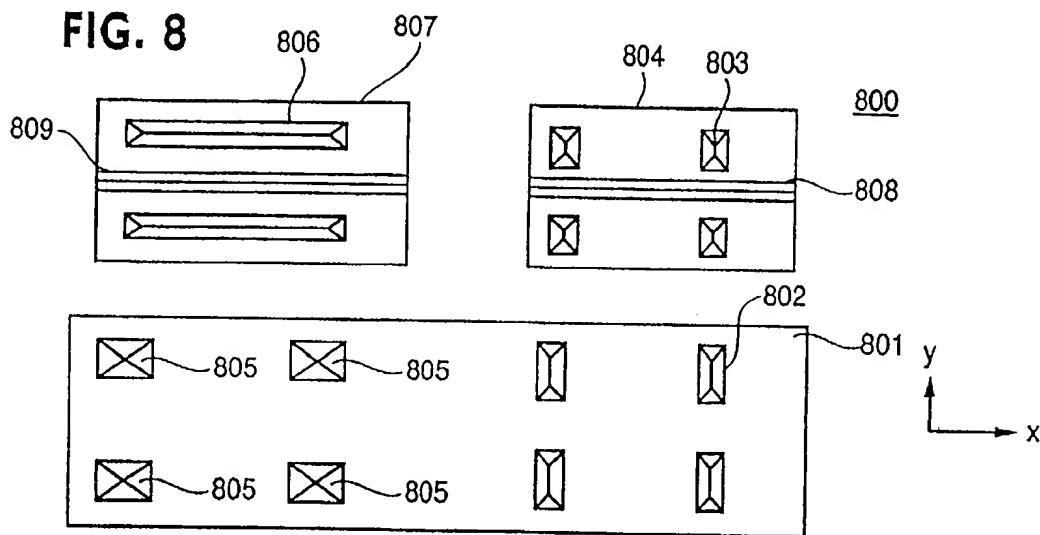
**FIG. 6**



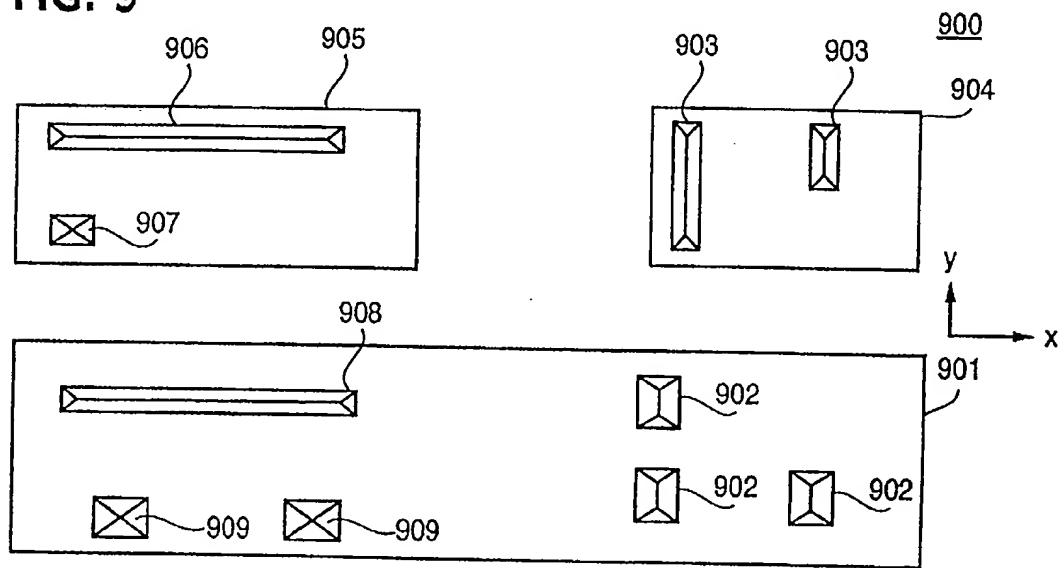
**FIG. 7**



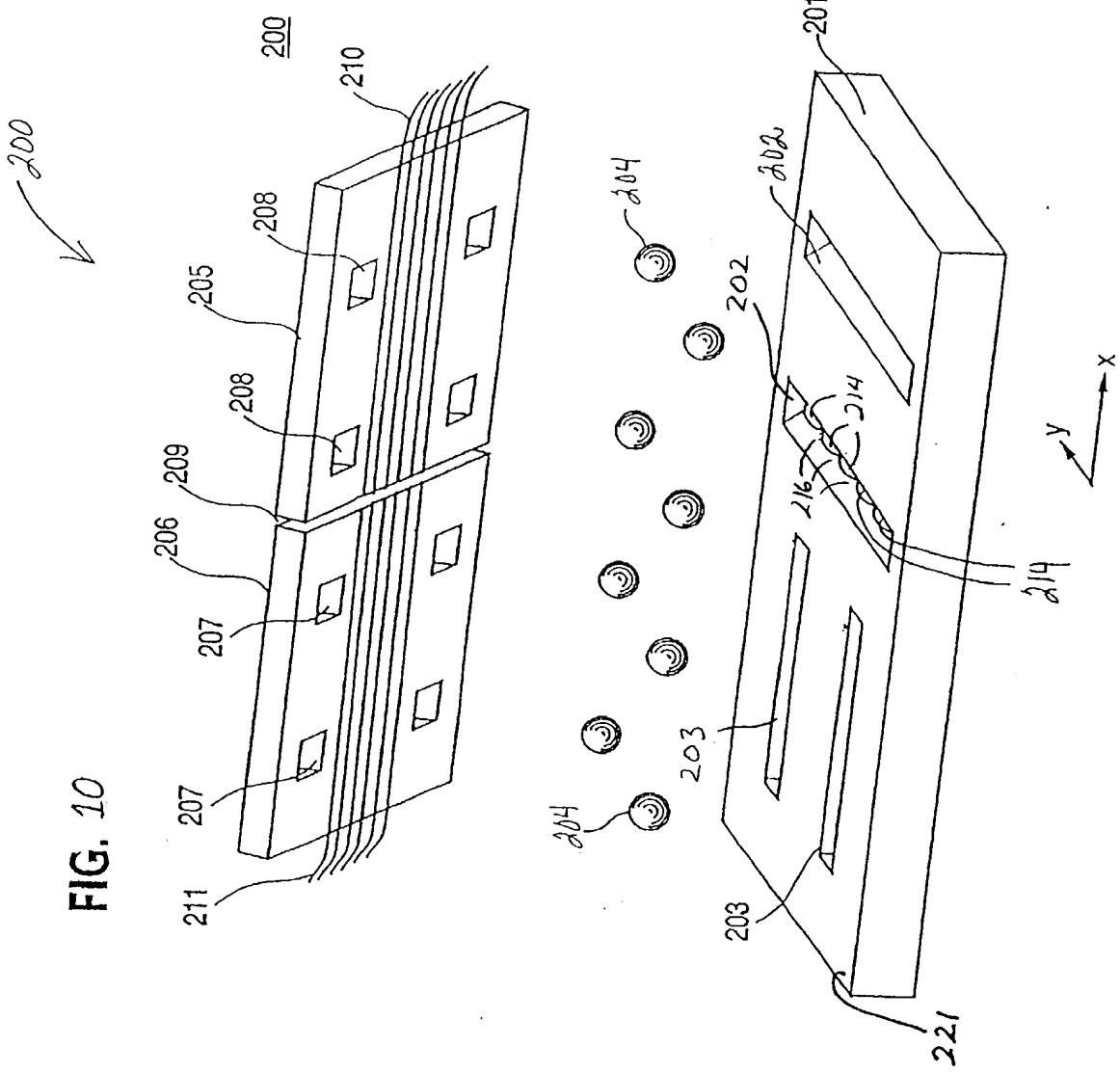
**FIG. 8**



**FIG. 9**



**FIG. 10**



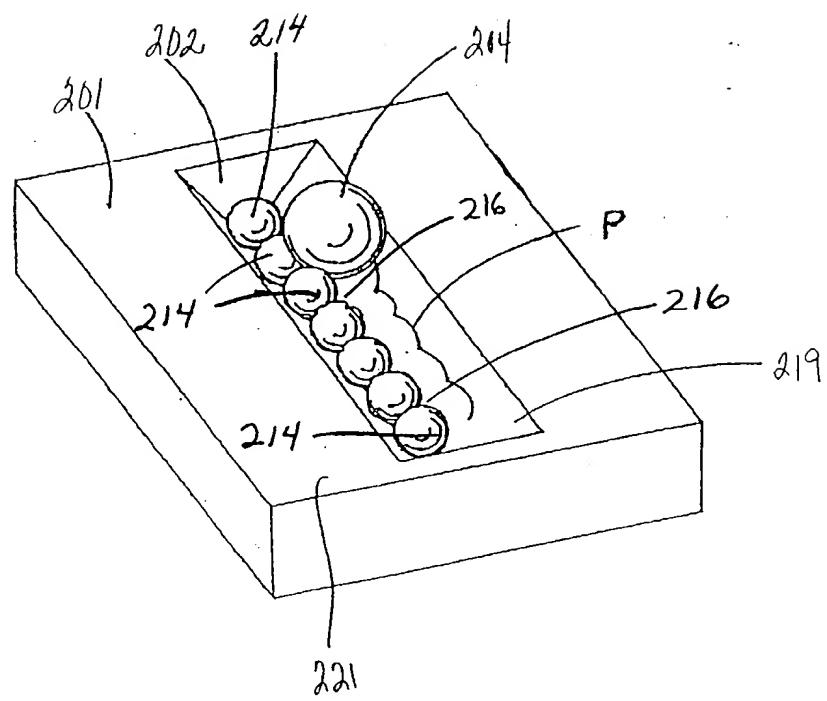


Fig. 11

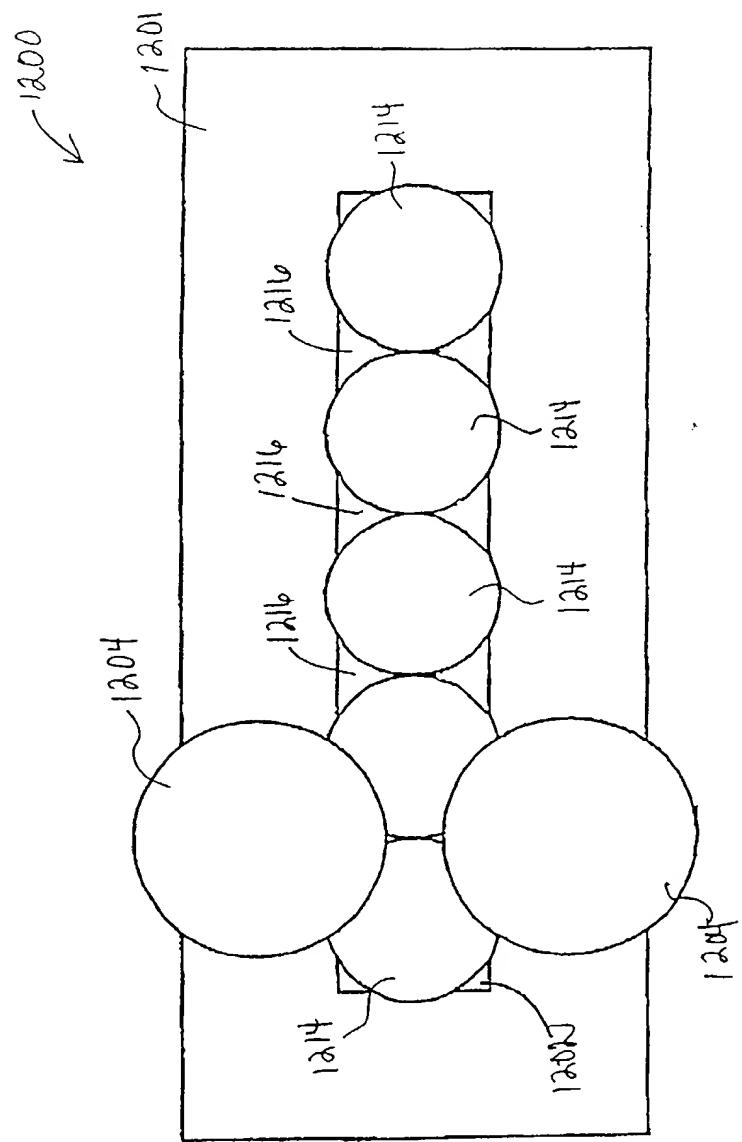


Fig. 12

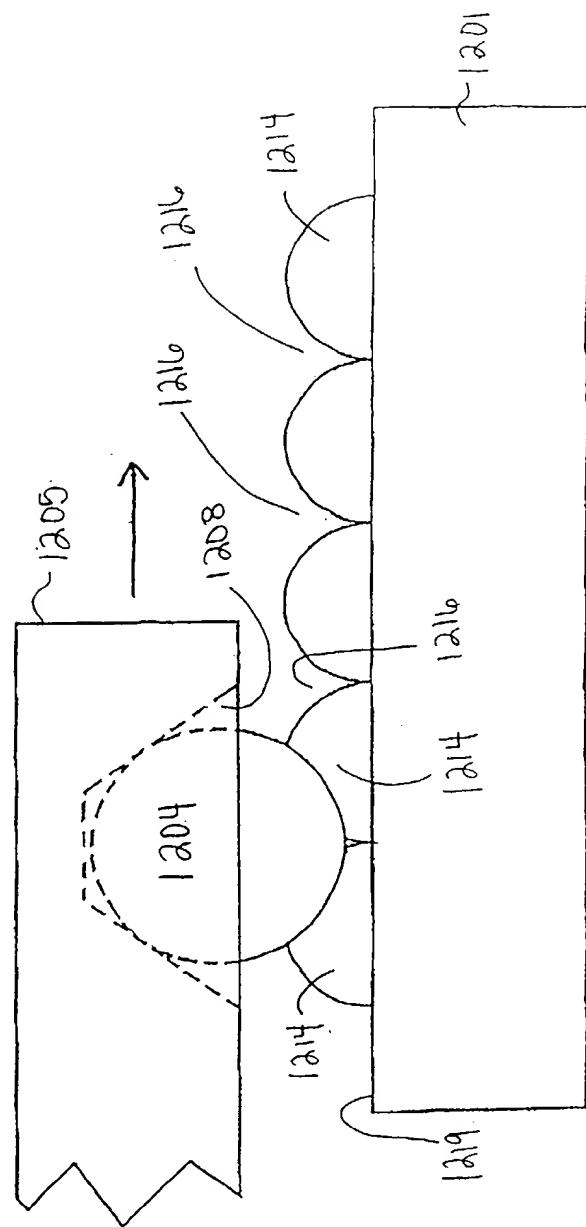


Fig. 13

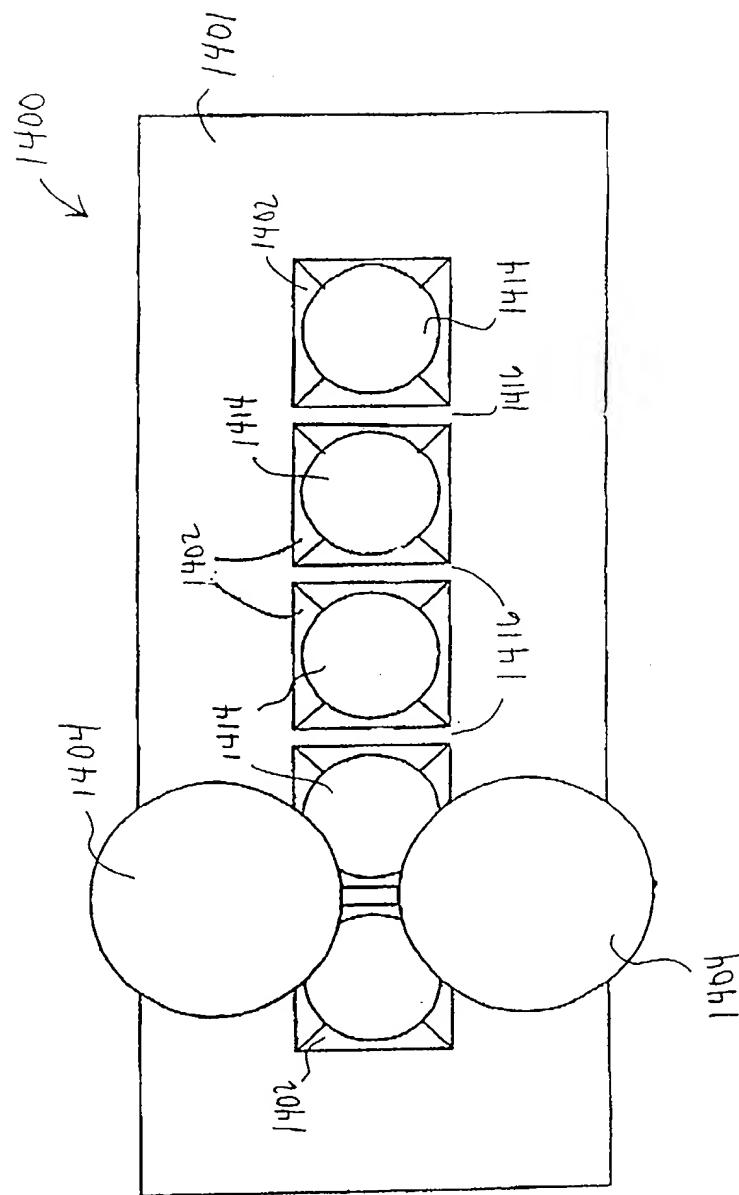


Fig. 14

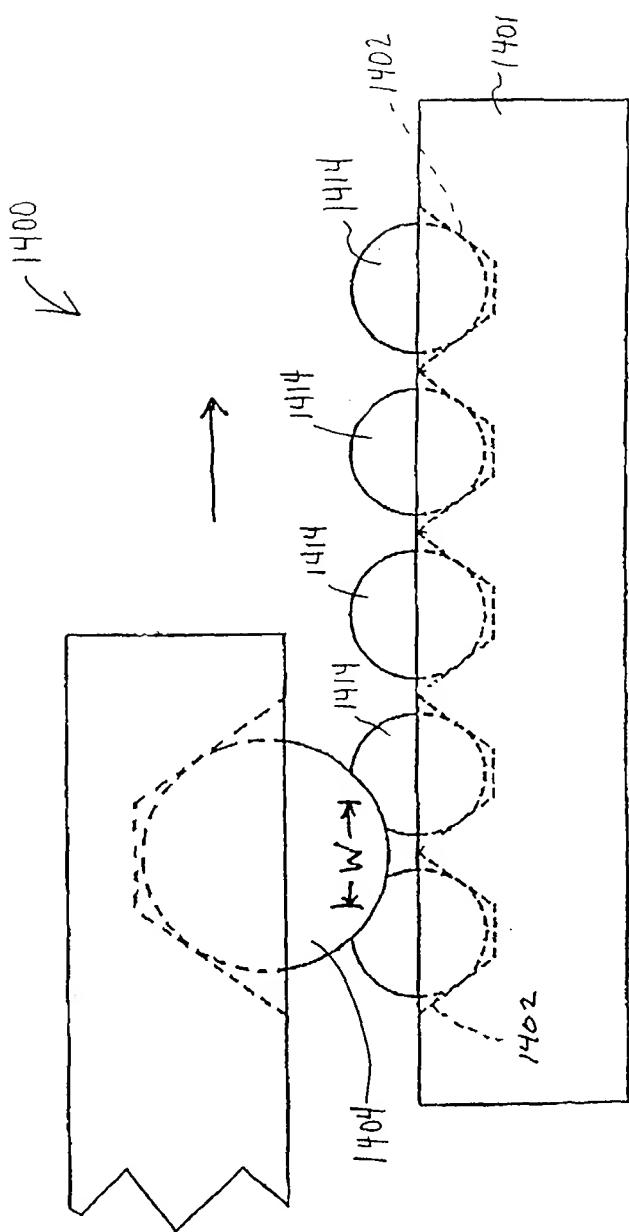


Fig. 15

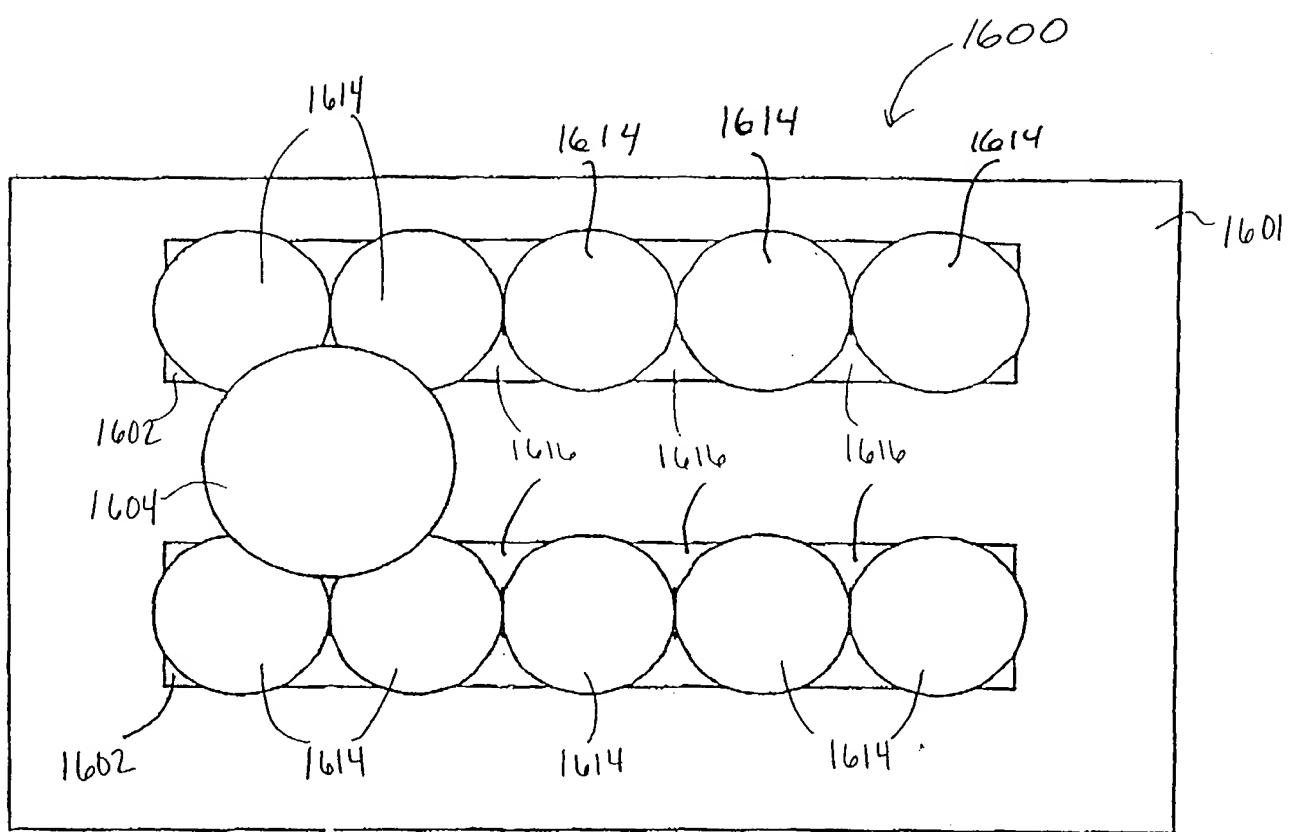


Fig. 16

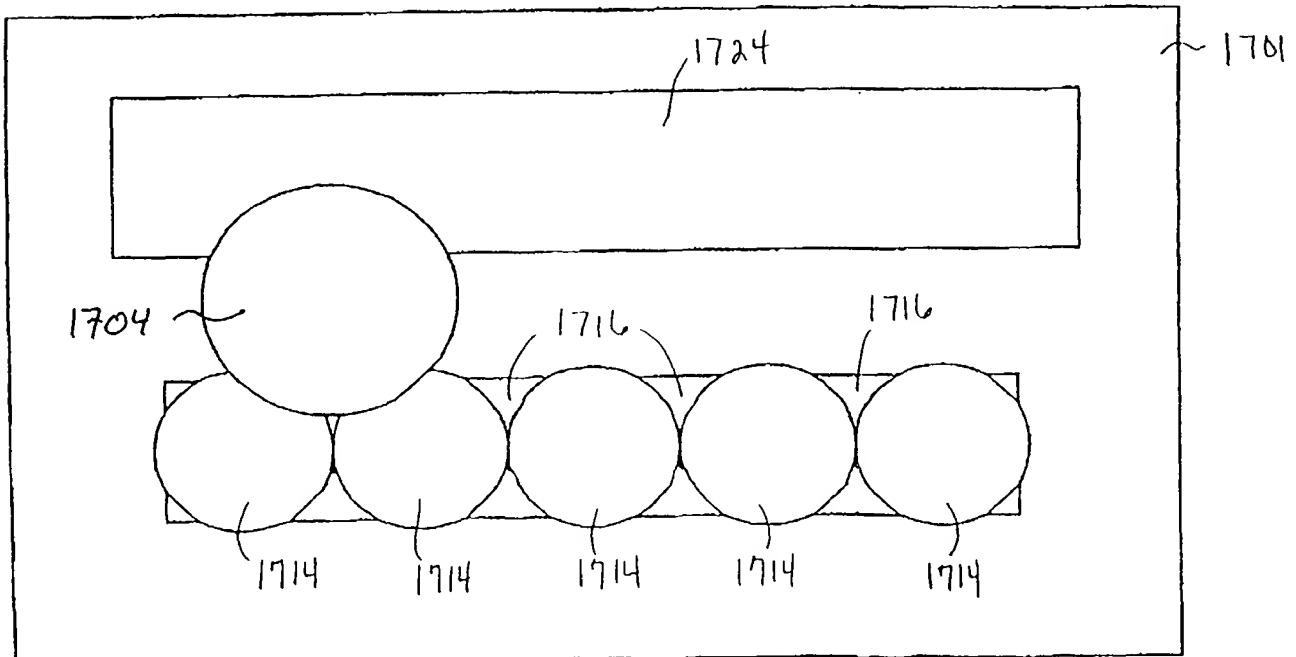


Fig. 17

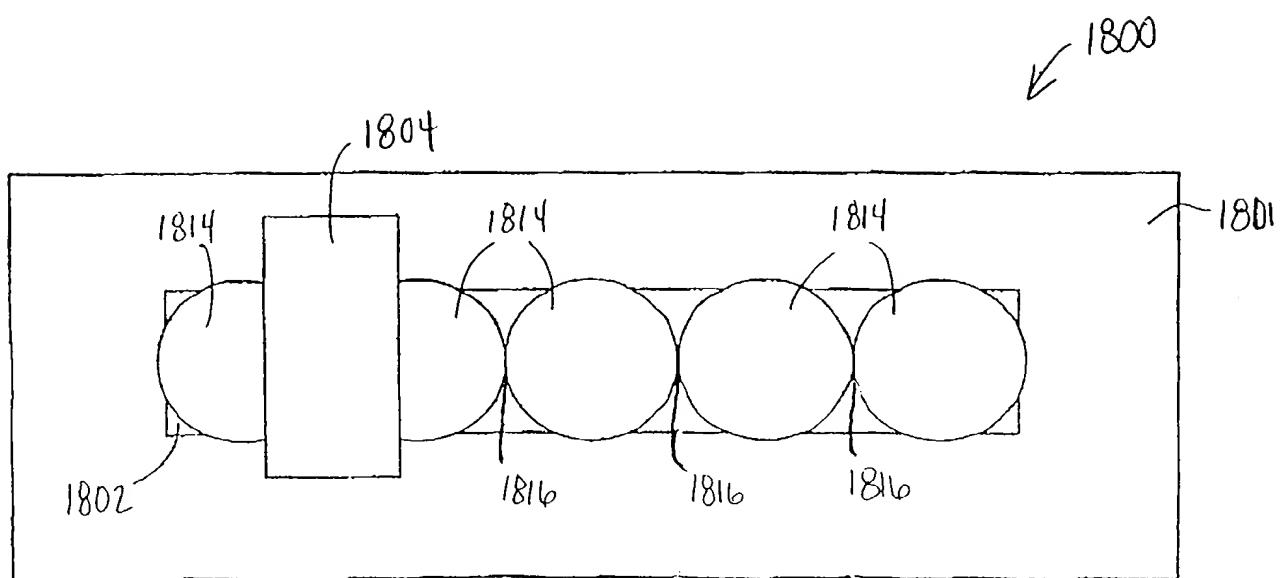


Fig. 18

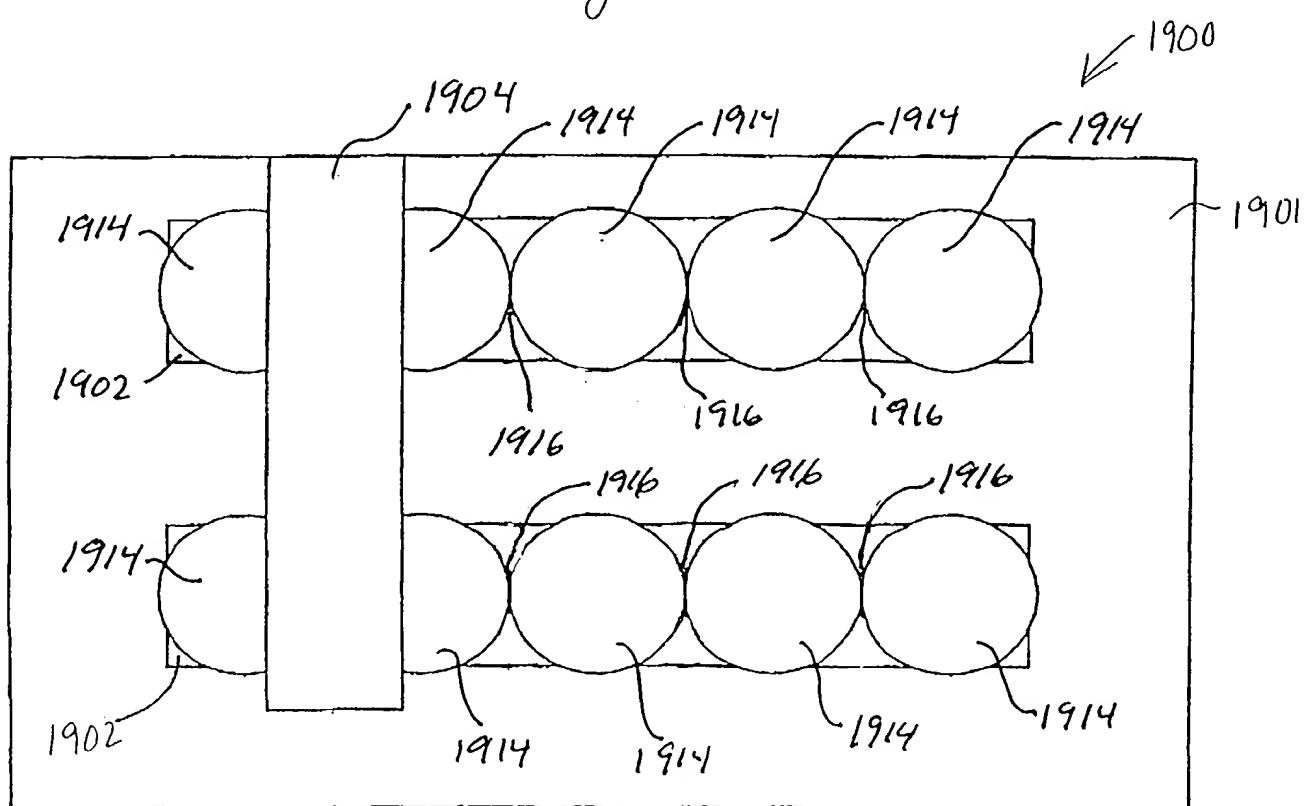


Fig. 19

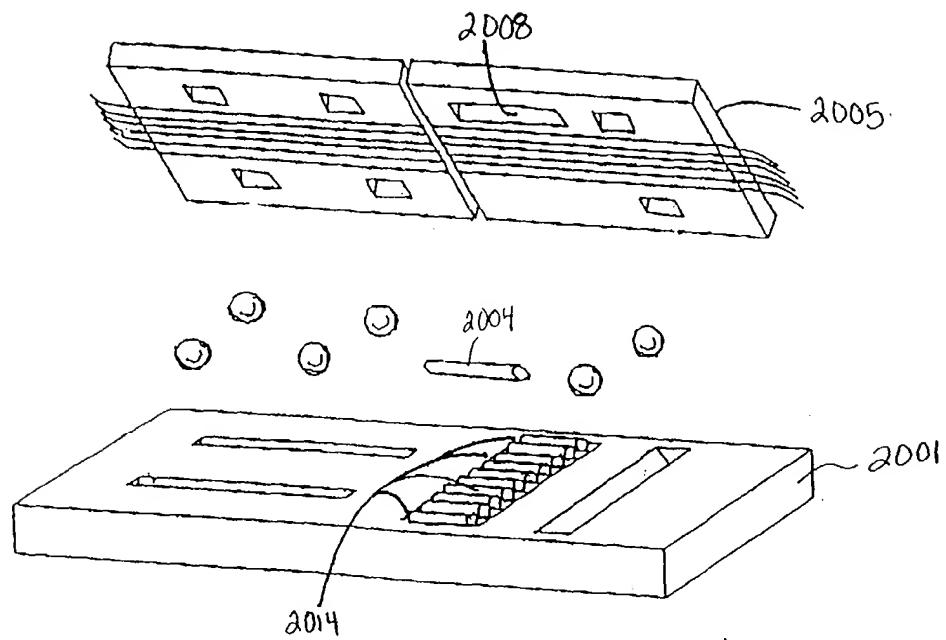


Fig. 20

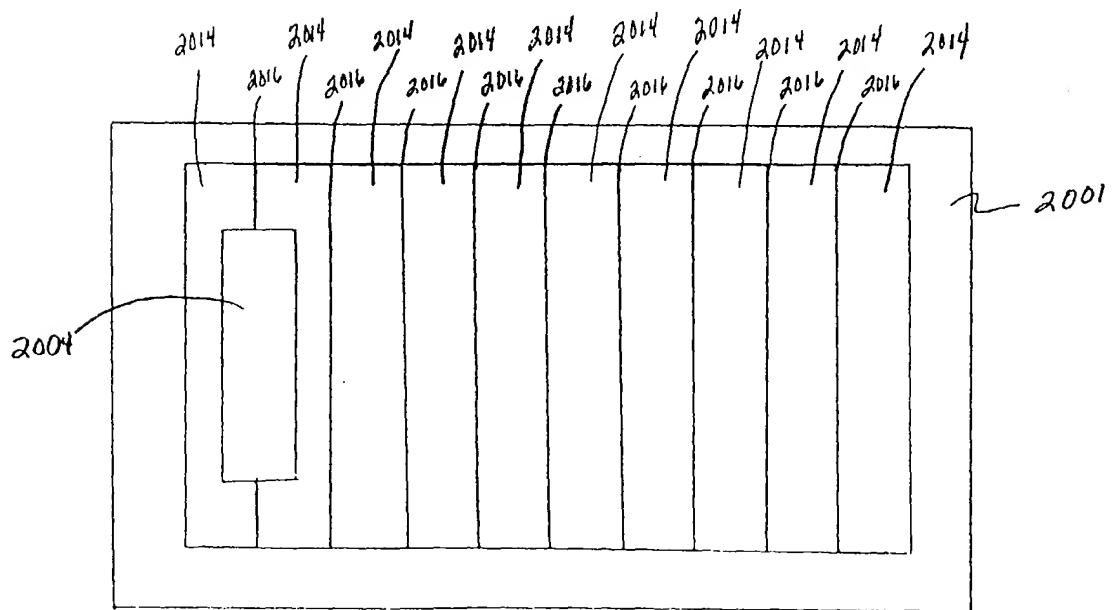


Fig. 21

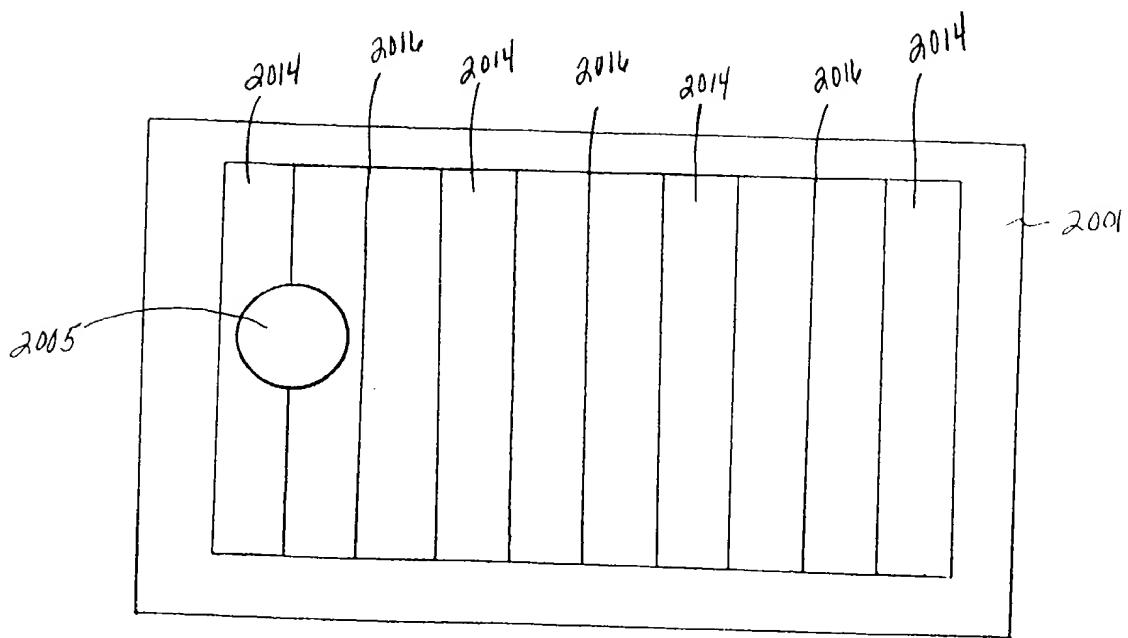


Fig. 22

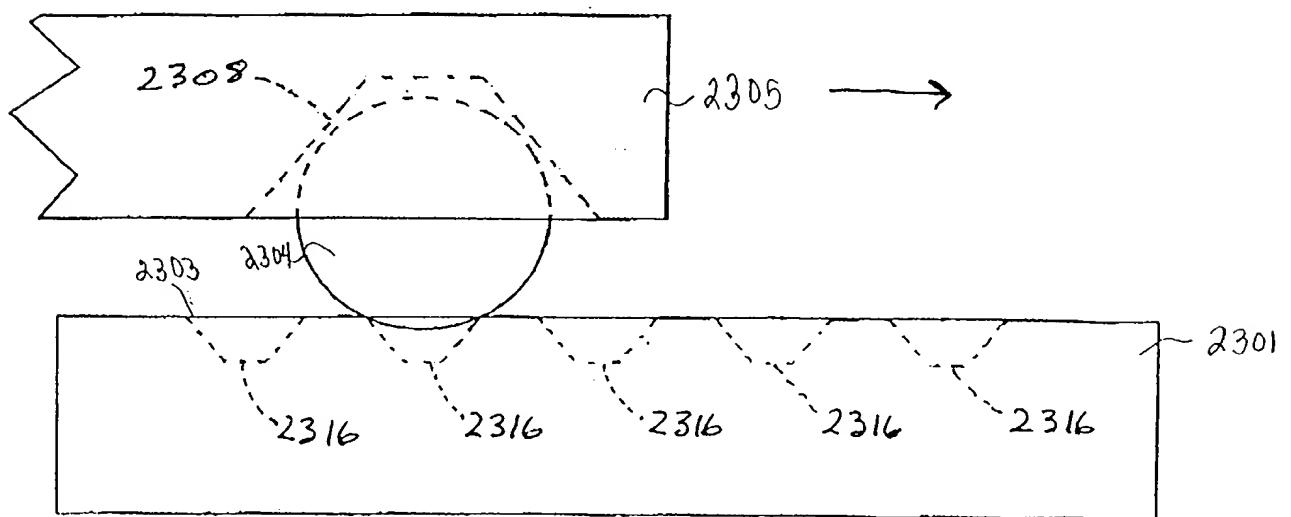
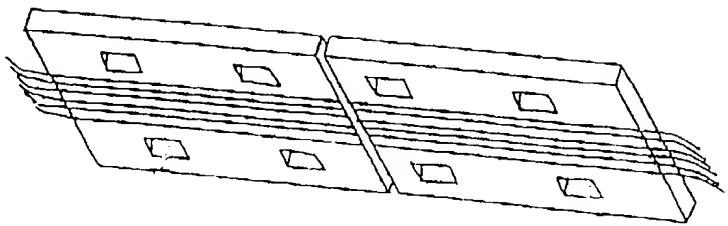


Fig. 23

✓ 2400



2404  
2404

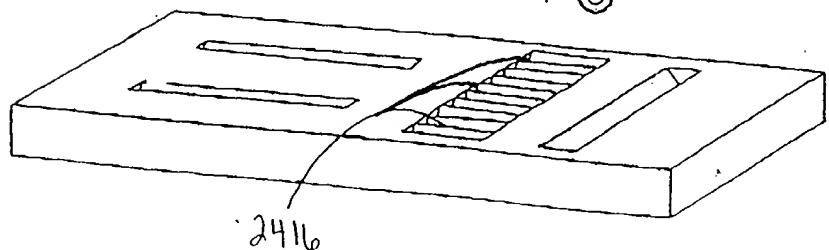
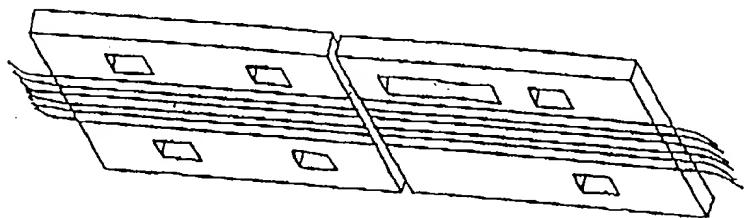
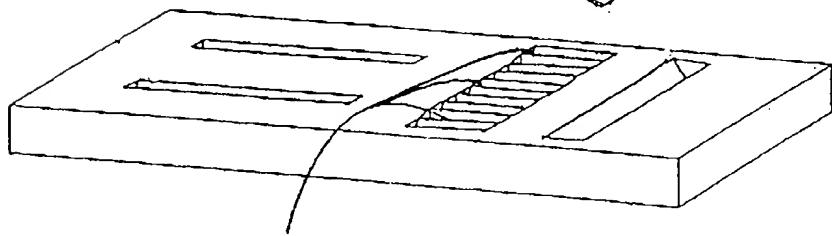


Fig. 24



2504



2416

Fig 25

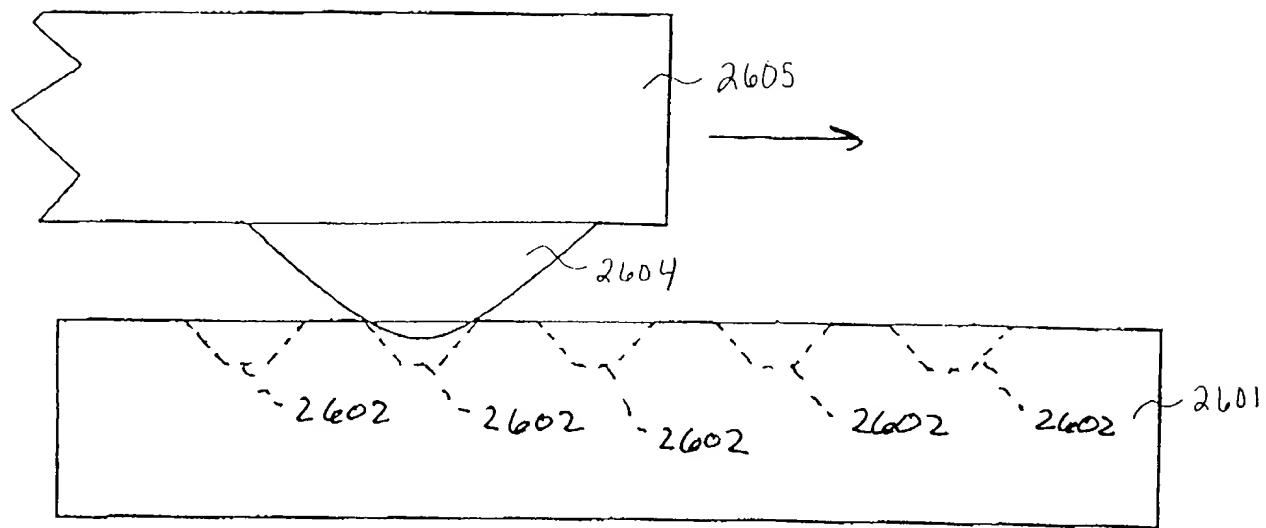


Fig. 26

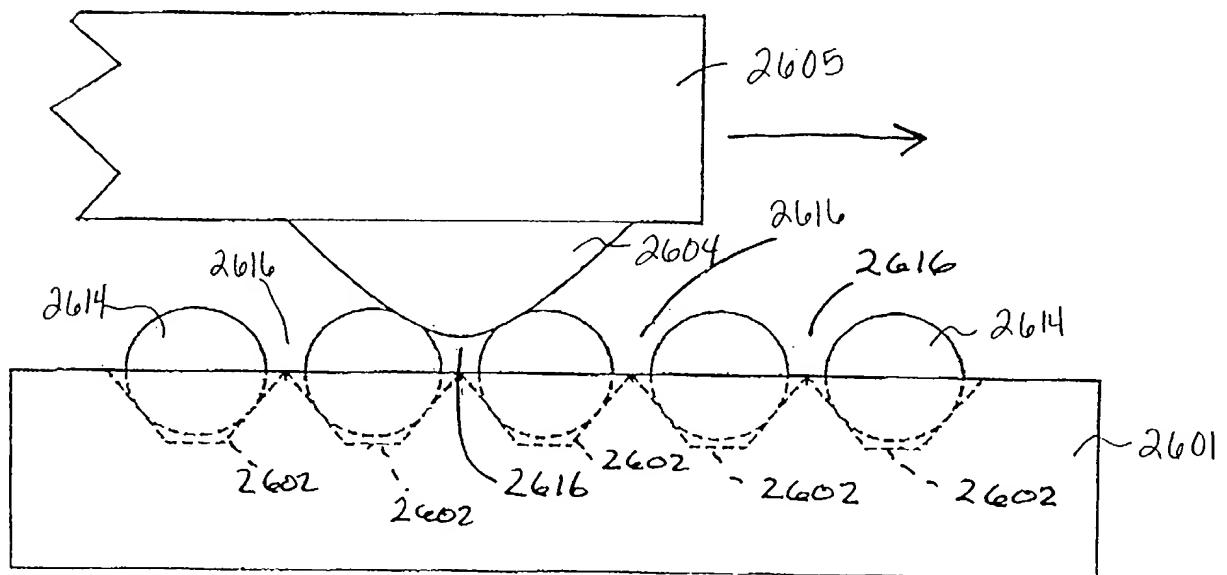


Fig. 27

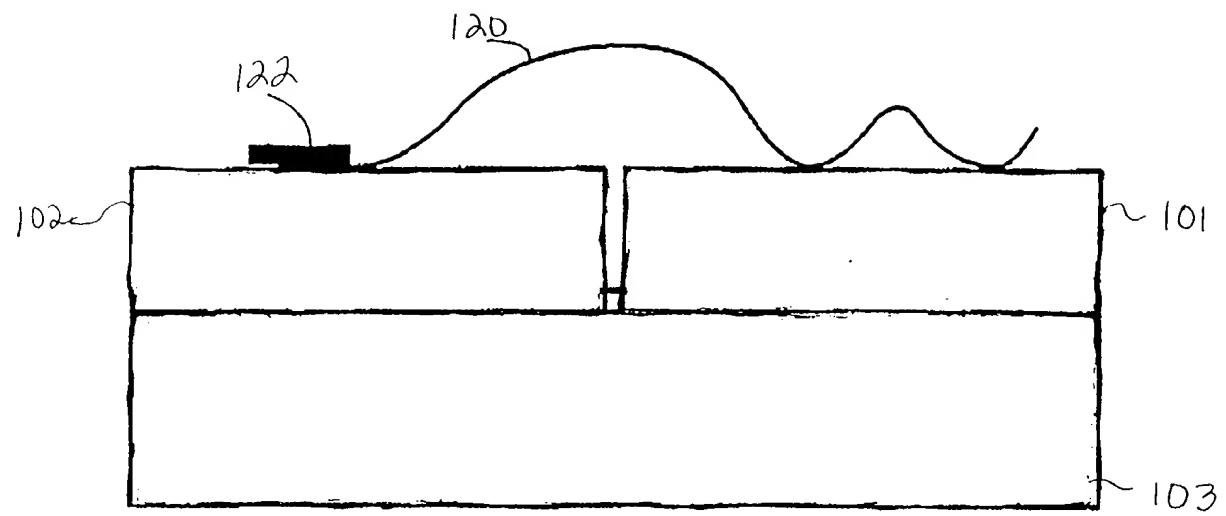


Fig. 28

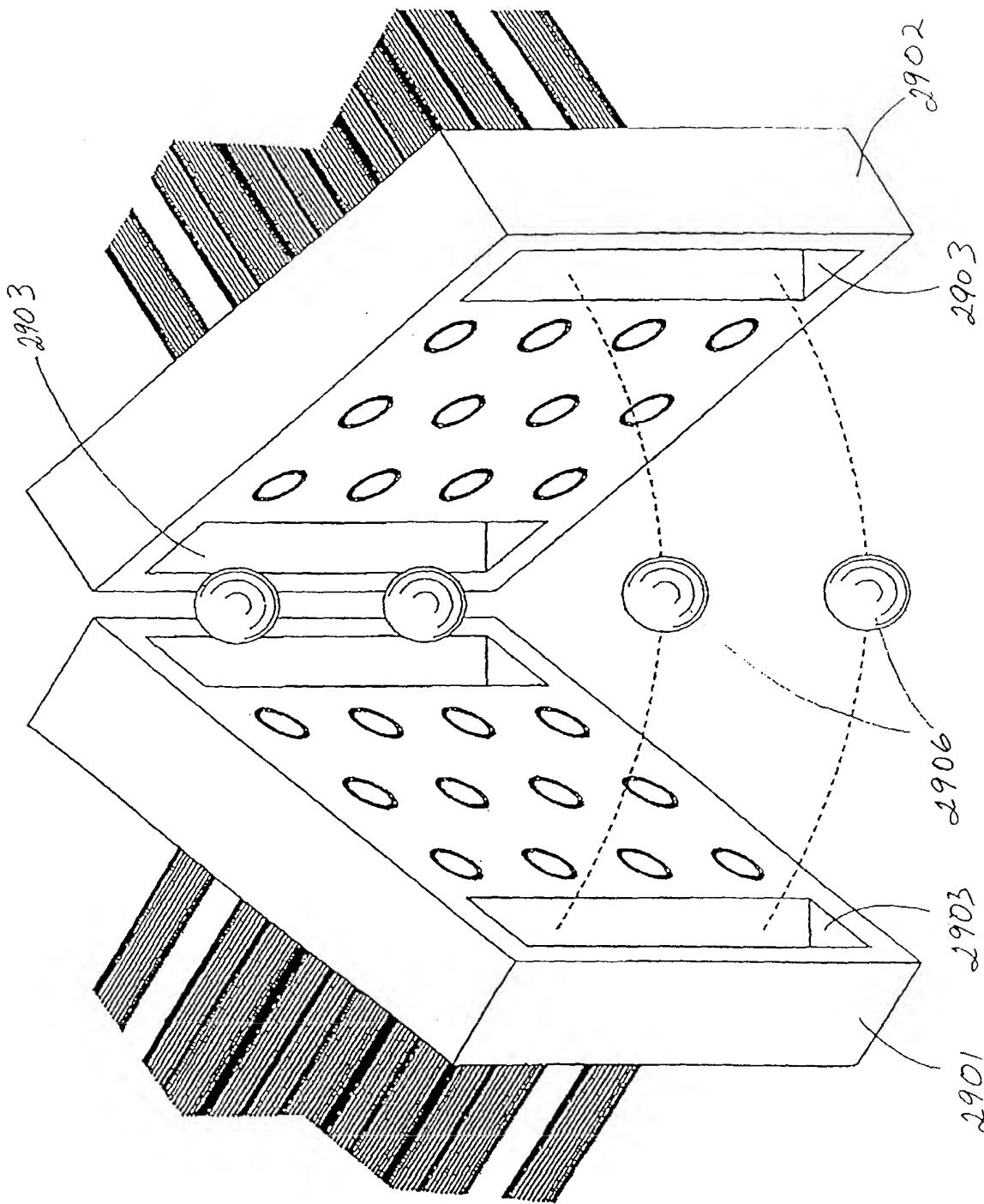


Fig. 29

## OPTICAL WAVEGUIDE SWITCH

5

### Cross-Reference to Related Applications

The present invention claims priority from U.S. Provisional Patent Application Number 60/197,154 entitled "Fiber Array Switch Having Micromachined Front Face," filed April 13, 2000. The present invention also claims priority from U.S. Provisional Patent Application Number 60/201,347 entitled "Optical Fiber Array Switches and Alternative Embodiments," filed May 2, 2000. The disclosures of the above captioned provisional patent applications are specifically incorporated by reference as though reproduced in their entirety herein.

15

### Field of the Invention

The present invention relates generally to routing to optical switches in waveguides, and specifically to an array (mxn) optical switch.

### 20 Background of the Invention

The increasing demand for high-speed voice and data communications has led to an increased reliance on optical communications, particularly optical fiber communications. The use of optical signals as a vehicle to carry channeled information at high speeds is preferred in many instances to carrying channeled information at other electromagnetic wavelengths/frequencies in media such as microwave transmission lines,

co-axial cable lines and twisted pair transmission lines. Advantages of optical media are, among others, high-channel capacity (bandwidth), greater immunity to electromagnetic interference, and lower propagation loss. In fact, it is common for high-speed optical communication systems to have signal rates in the range of approximately several Giga bits per second (Gbit/sec) to approximately several tens of Gbit/sec.

One way of carrying information in an optical communication system, for example an optical network, is via an array of optical fibers. Ultimately, the optical fiber array may be coupled to another array of waveguides, such as another optical fiber array, or a waveguide array of an optoelectronic integrated circuit (OEIC). In order to assure the accuracy of the coupling of the fiber array to another waveguide array, it becomes important to accurately position each optical fiber in the array.

Optical switches serve a variety of applications in optical communication systems. Once such variety of optical switches are mechanical switches. Mechanical optical switches have been used in a variety of optical fiber routing applications to switch between particular optical signal pads to provide reliable optical transmission routes for carrying optical signals.

Many mechanical optical switch configurations which are commercially available are typically characterized as either optical-component-moving-type or fiber-moving-type switch configurations. Illustratively, optical-component-moving-type switches include configurations that employ movable optical element (e.g. mirrors or prisms) to selectively redirect signals from an end of a first optical fiber to an end from a second optical fiber wherein the optical fibers are arranged in a parallel manner with their ends

adjacent one another. While beneficial optical-component-moving-type switches typically elaborate and often too expensive for large scale implementation.

Conventional fiber-moving-type switch configurations may provide multiple-port switching. However, these types of optical switches suffer from complexity, expense and 5 chronically poor alignment which requires frequent and labor intensive adjustment. The relative complexity of conventional fiber-moving-type switches has resulted in prohibitive cost and relatively high alignment tolerances which ultimately impair the performance of the device.

Accordingly, what is needed is a relatively simple, inexpensive, mechanical stable 10 optical switch configuration capable of providing multiple-port switching in a variety of optical applications.

### **Summary of the Invention**

According to an exemplary embodiment of the present invention, an optical 15 switch includes a first waveguide holding member and a second waveguide holding member disposed on a substrate. The first waveguide holding member moves relative to the second waveguide holding member. A movement guiding member guides the motion of the first waveguide holding member.

Advantageously, the first waveguide holding member moves transversely relative 20 to the second waveguide holding member. The transverse motion enables selective coupling between a waveguide in the first waveguide holding member and a waveguide in the second holding member. Through this transverse motion of the second waveguide holding member, an optical switching action may be implemented.

**Brief Description of the Drawings**

The invention is best understood from the following detailed description when read with the accompanying drawing figures. It is emphasized that the various features 5 are not necessarily drawn to scale. In fact, the dimensions may be arbitrarily increased or decreased for clarity of discussion.

Fig. 1 is a perspective view of an optical fiber switch according to an exemplary embodiment of the present invention.

Fig. 2 is an exploded view of an optical switch according to an exemplary 10 embodiment of the present invention.

Fig. 3 is an exploded view of an optical switch according to an exemplary embodiment of the present invention.

Fig. 4 is a top view of an optical switch according to yet another exemplary embodiment of the present invention.

15 Fig. 5 is a top view of an optical switch according to yet another exemplary embodiment of the present invention.

Fig. 6-9 are top views of substrates and waveguide holding members according to exemplary embodiments of the present invention.

20 **Defined Terms**

1. As used herein, the term "on" may be directly on. Alternatively "on" may mean "over."

2. As used herein, "longitudinal" means parallel to the optic axis of a waveguide (x-direction herein); "transverse" means perpendicular to the optic axis of a waveguide (y-direction herein).
3. As used herein, "movement guiding member" means a device or structure which constrains movement to substantially linear motion.

5

### **Detailed Description**

In the following detailed description, for purposes of explanation and not limitation, exemplary embodiments disclosing specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one having ordinary skill in the art having had the benefit of the present disclosure, that the present invention may be practiced in other embodiments that depart from the specific details disclosed herein. Moreover, descriptions of well-known devices, methods and materials may be omitted so as to not obscure the description of the present invention.

10 15

According to an exemplary embodiment of the present invention, an optical switch includes a first waveguide holding member and a second waveguide holding member disposed on a substrate. The first waveguide holding member moves relative to the second waveguide holding member. A movement guiding member guides the motion of the first waveguide holding member.

20 Advantageously, the first waveguide holding member moves transversely relative to the second waveguide holding member. The traverse motion enables selective coupling between a waveguide in the first waveguide holding member and a waveguide

in the second waveguide holding member. Through this transverse motion of the second waveguide holding member, an optical switching action may be implemented.

Fig. 1 shows an optical switch 100 according to an illustrative embodiment of the present invention. A first waveguide holding member 101 and a second waveguide holding member 102 are disposed over a substrate 103. Optical waveguides 105 and 106 are disposed in the first waveguide holding member 101 and the second waveguide holding member 102, respectively. The waveguides 105 and 106 within the first and second waveguide holding members are selectively optically coupled to one another. To this end, a gap spacing 104 between the first waveguide holding member 101 and the second waveguide holding member 102 may be set so that efficient optical coupling is achieved between selected waveguides in the first waveguide holding member 101 and the second waveguide holding member 102 is achieved.

After the gap spacing 104 has been set via longitudinal motion (x-direction) of the second waveguide holding member 102 relative to the first waveguide holding member 101, transverse (y-direction) motion may be carried out to selectively couple/decouple optical waveguide(s) in the first waveguide holding member 101 to an optical waveguide(s) in the second waveguide holding member 102. Accordingly, by virtue of the transverse motion of the first waveguide holding member 101 relative to the second waveguide holding member 102 the coupling/decoupling of waveguides may be used to achieve optical switching between selected waveguides.

Illustratively, the motion of the first waveguide holding member 101 and the second waveguide holding member 102 may be through the use of known mechanical

actuators. These include, but are not limited to, electromagnetic, piezoelectric, microelectro-mechanical system (MEMs), and hydraulic devices.

Illustratively, waveguides 105 and 106 are optical fibers. However, they may be planar waveguides as well. The waveguides 105 and 106 may be disposed on the lower 5 surfaces of the first and second waveguide holding members 101 and 102, respectively. This substantially avoids alignment problems due to variations in thicknesses of first and second waveguide holding members 101 and 102, respectively. Moreover, this placement of waveguides 105 and 106 substantially avoids front-side and back-side alignment errors. However, the optical waveguides may be located on the top surfaces of 10 or within first and second waveguide holding members 101 and 102.

In the illustrative embodiment shown in Fig. 1, a movement guiding member (not shown) may be disposed so that the first waveguide holding member 101 moves transversely. Moreover, a similar movement guiding member may be disposed so that the second waveguide holding member 102 moves longitudinally. The longitudinal 15 motion of the second waveguide holding member 102 allows adjustment of the gap spacing 104. For purposes of illustration and not limitation, after the gap spacing 104 has been set, the second waveguide holding member 102 may be secured in position by use of a suitable adhesive. For example, a suitable epoxy may be used to secure the second waveguide holding member 102 in position. Moreover, the second waveguide holding 20 member 102 may be adhered to the substrate 103 by thermo-compression bonding with aluminum. The gap spacing may be in the range of approximately of less than approximately  $1 \mu m$  to approximately  $15 \mu m$ . Finally, it is of interest to note that the second waveguide holding member 102 may be located so that the gap spacing is set

without longitudinal motion. This may be achieved through use of alignment fiducials or other suitable devices.

In this illustrative embodiment, the second waveguide holding member 102 may also be capable of transverse (y-direction) motion. This may be accomplished using a 5 suitably disposed movement guiding member to achieve transverse motion. As such, the switching capabilities of the optical switch 100 may be achieved by one or both of the first and second waveguide holding members 101 and 102, respectively.

Turning to Fig. 2, a perspective view of an optical switch 200 according to an exemplary embodiment of the present invention is shown. A substrate 201 illustratively 10 includes longitudinal grooves 203 and transverse grooves 204. The longitudinal grooves 203 and transverse grooves 204 are adapted to receive positioning members 205. The positioning members 205 are illustratively microspheres or other suitable sphere-shaped objects. The positioning members 205 are disposed between the longitudinal grooves 203 and pits 207 disposed in second waveguide holding member 206. Positioning 15 members 205 are also positioned between transverse grooves 204 and pits 208 disposed in first waveguide holding member 205. As can be readily appreciate the longitudinal and transverse grooves 201 and 202 of the substrate and the 208, 207 pits on the first and second waveguide holding members 205 and 206, respectively are on opposing surfaces thereof.

20 Illustratively, transverse motion of the first waveguide holding member 205 is achieved by motion of the positioning members 205 in grooves 204. The positioning members 205 are constrained by pits 208. Likewise, longitudinal motion of second waveguide holding member 206 is achieved through the motion of positioning members

205 in longitudinal grooves 203. The positioning members 205 are constrained in pits 207 in the second waveguide holding member 206.

As described in more detail above, the longitudinal motion may be used to adjust gap spacing 209 between the first waveguide holding member 205 and the second 5 waveguide holding member 206. Transverse motion of the first waveguide holding member 205 may be used to achieve switching between waveguides 210 and 211. To this end, switching is achieved by selectively coupling/decoupling waveguides 210 disposed in first waveguide holding member 205 with waveguides 210 disposed in second waveguide holding member 206. Finally, it is of interest to note that waveguides 10 210 and 211 may be disposed on the lower surfaces of the first and second waveguide holding members 205 and 206, respectively. They may be held in v-grooves (not shown), for example. Moreover, the waveguides 210 and 211 may be disposed on the top surfaces of the waveguide holding members 205 and 206, respectively. Finally, waveguides 210 and 211 may be disposed within waveguide holding members 205 and 15 206, thereby being integer parts thereof.

Fig. 3 shows an optical switch 300 according to another illustrative embodiment of the present invention. A substrate 301 has transverse grooves 302 and longitudinal grooves 303. Positioning members 304 are disposed between transverse grooves 302 and pits 305 in first waveguide holding member 306. The positioning members 304 are 20 constrained in pits 305 and move along longitudinal grooves 302, which enables transverse motion of first waveguide holding member 306 in a manner similar to that described in connection with the illustrative embodiment of Fig. 2.

Positioning members 307 are disposed between longitudinal grooves 303 in substrate 301 and grooves 308 dispose in second waveguide holding member 309. Positioning members 307 are illustratively cylindrical-shaped rod elements which enable the longitudinal motion (x-direction) of first waveguide holding member 306.

5 Illustratively, positioning members 307 may be sections of optical fiber or micromachined rods. Moreover, positioning members may be glass, metal or ceramic. Similar to the illustrative embodiment of Figs. 1 and 2 the longitudinal motion of second waveguide holding member 309 enables the adjustment of the gap spacing 310 between the first waveguide holding member 306 and the second waveguide holder member 309

10 to enable coupling of optical fibers 311 and 312.

In the illustrative embodiments of Figs. 2 and 3, the grooves 202, 203, 302, 303 and 308 are illustratively v-shaped grooves. The pits 207, 208 and 305 are illustratively inverted pyramidal-shaped pits. The grooves and pits are formed by illustrative techniques described below. Finally, in the illustrative embodiments of Figs. 2 and 3, 15 first waveguide holding members 205 and 306 and second waveguide holder member 206 each include four pits which constrain positioning members 204 and 304. As can be readily appreciated, at least three pits are required for stability and motion constrain. Other numbers of pits and positioning members may be used in keeping with the present invention. Finally, grooves 202, 203, 302, 303 and 308 and pits 207, 208 and 305 may be 20 lined with a suitable material to reduce wear and/or friction.

The inverted pyramidal pits and grooves may be formed by anisotropic wet etching of a monocrystalline material. Illustratively, monocrystalline material may be selectively etched according to known techniques. The surfaces of the inverted

pyramidal pits are along well-defined principle planes of the monocrystalline material.

One such known technique for anisotropic etching of monocrystalline material may be found in U.S. Patent 4,210,923 to North, et al., the disclosure of which is specifically incorporated by reference herein. Of course, other known etching techniques may (wet or dry) be used to form the pits and grooves. Moreover, other materials may be used for the substrate and first and second waveguide holding members. These include, but are not limited to, glass, quartz, metal or plastic. The grooves and pits may be formed therein by known techniques.

In the illustrative embodiments of the present invention, a movement guiding member may comprise a positioning member disposed between a pit and a groove. The pits may be located in the waveguide holding member or in the substrate depending on application. Moreover, a movement guiding member may comprise a positioning member disposed between two grooves. Again, the grooves may be located in the substrate and in the waveguide holding member. Again, this is merely illustrative of the movement guiding members of the exemplary embodiments of the present invention, and other movement guiding members may be used in carrying out the invention.

Fig. 4 shows an optical switch 400 according to an illustrative embodiment of the present invention. A substrate 401 has transverse v-grooves 402 disposed therein. The substrate 401 further includes longitudinal v-grooves 403. A first waveguide holding member 404 includes first waveguides 405. The waveguides 405 may be disposed on top of the first waveguide holding member 404; on the bottom of first waveguide holding member 405; or within the first waveguide holding member 404. A second waveguide holding member 406 includes second waveguides 407. The second waveguides 407 may

be disposed on a top surface of second waveguide holding member 406; a bottom surface of second waveguide holding member 406; or within the second waveguide holding member 406. Waveguides 405 and 407 are illustratively optical fibers. However, waveguides 405 and 407 may be planar waveguides. In the illustrative embodiment of 5 Fig. 4, first positioning members 408 are disposed in pits 409 in the first waveguide holding member 404. Likewise, second positioning members 410 are disposed in pits 411 in the second waveguide holding member 406.

As described above, the pits 409 are illustratively inverted pyramidal pits. The 10 first positioning members 408 are relatively self-contained within the pits 409, and cooperatively engage the longitudinal grooves 403. Illustratively, a movement guiding member may comprise a first positioning member 408 disposed between a pit 409 and a longitudinal groove 403. In the illustrative embodiment shown in Fig. 4, this translates to motion of the first waveguide holding member 404 in the  $\pm$  x-direction. As can be readily appreciated, motion in the  $\pm$  x-direction facilitates the longitudinal alignment of 15 the first waveguides 405 with the second waveguides 407. Particularly, the constrained linear motion of the first waveguide holding member 404 in the longitudinal direction enables the proper selection of the gap spacing 412.

The second positioning members 410 are disposed in pits 411. Again, the second 20 positioning members 410 are constrained in the pits 411, which are illustratively inverted pyramids. The second positioning members 410 are constrained by grooves 402 to move in the traverse direction. In the illustrative embodiment shown in Fig. 4, this results in the transverse motion of the second waveguide holding member 406 in the  $\pm$  y-direction.

Illustratively, a movement guiding member may comprise a second positioning member 410 disposed between a pit 411 and a transverse groove 413. The transverse motion of waveguides 407 relative to waveguides 405 enables the selective coupling/decoupling of waveguides. This facilitates the switching of a signal from one 5 waveguide to another. For example, an optical signal may be traversing waveguide 413 of the first waveguide holding member 404. This waveguide may be coupled to waveguide 414 disposed in second waveguide holding member 406. As can be readily appreciated, movement of the second waveguide holding member 406 in either the + y-direction or the – y-direction may uncouple waveguide 413 from waveguide 414.

10 Movement in the + y-direction, for example of a predetermined distance may enable coupling of the optical signal traversing waveguide 413 into waveguide 415. As such, coupling of the optical signal is “switched” from waveguide 414 to waveguide 415.

In the exemplary embodiment, waveguides 405 and 407 each comprise a row of three waveguides. Of course, this is for purposes of illustration, and more or fewer 15 waveguides may be used. Moreover, as can be readily appreciated, waveguides 405 of the first waveguide holding member 404 may be a linear array (a row) or a matrix of a suitable number of rows and columns of optical waveguides. Likewise, optical waveguides 407 of the second waveguide holding member 406 may also be a linear array (a row) or a matrix having a suitable number of rows and columns. Moreover, the pitch 20 between waveguide 405 may be the same or different than that of waveguides 407. As such, sophisticated switching schemes may be realized through the transverse motion of the second waveguide holding member 406 relative to the first waveguide holding member 404.

Fig. 5 shows an optical switch 500 according to another illustrative embodiment of the present invention. A substrate 501 has transverse grooves 502 disposed therein. The substrate 501 also includes longitudinal grooves 503. The transverse grooves 502 receive positioning members 504 which are disposed in pits 505 in the second waveguide holding member 506. In the present illustrative embodiment, movement guiding members may comprise positioning member 504 between pits 505 and transverse grooves 502.

The motion of the positioning members 505 in the transverse grooves 502 enables the transverse motion (y-direction) of the second waveguide holding member 506 relative to the first waveguide holding member 507. The transverse motion enables the selective coupling/decoupling of optical waveguides 508, 509 and 510 to waveguides 511, 512 and 513, respectively. Transverse motion of the second waveguide holding member 506 would change this coupling, enabling a switching action.

In the illustrative embodiment of Fig. 5, positioning members 514 are disposed in pits 515 in the second waveguide holding member 507. As can be readily appreciated, the engagement of the positioning members 514 within the longitudinal grooves 503 in the substrate 501 enables longitudinal movement (x-direction) of the second waveguide holding member 507. According to the illustrative embodiment of Fig. 5, the second waveguide holding member 507 may have an endface 516 which is polished. The gap spacing 517 may be accurately determined by elements 518 which are illustratively ball lenses or microspheres disposed in grooves 519 in the first waveguide holding member 506. The gap spacing 517 is illustratively in the range of approximately less than 1  $\mu m$  to approximately 15  $\mu m$ .

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Figs. 6 – 9 are illustrative embodiments of the substrate and waveguide holding members according to the present invention. These embodiments are intended to be illustrative of different combinations of grooves and pits which will allow the relative transverse motion of the first and second waveguide holding members for optical 5 switching. These exemplary embodiments also provide longitudinal motion to adjust a gap spacing between the first and second waveguide holding members. These embodiments are intended to be illustrative, and in no way exhaustive of the combinations of the location of grooves and pits that can be used to carry out the invention of the present disclosure. As such, these variations and combinations that 10 would be readily apparent to one having ordinary skill in the art are within the scope of the appended claims and equivalents thereof.

Fig. 6 shows the elements of an optical switch 600 according to an illustrative embodiment of the present invention. A substrate 601 includes grooves 602 and pits 603. Again, the grooves 602 and pits 603 are fabricated by known techniques as described in 15 detail above. The grooves 602 and pits 603 are adapted to receive positioning members (not shown) such as those described in the connection with the illustrative embodiments above. A first waveguide holding member 604 includes grooves 605. The grooves 605 having the positioning members (not shown) therein which enable the transverse motion (y-direction) of the first waveguide holding member 604. The second waveguide holding 20 member 606 has grooves 607 therein. The grooves 607 which are adapted to receive the positioning members (not shown) enable the longitudinal motion (x-direction) of the second waveguide holding member 606. Again, the transverse motion of the first waveguide holding member 604 relative to the second waveguide holding member 606

enables the switching operation of waveguides 608 and 609. The longitudinal motion of the second waveguide holding member 606 enables the optical coupling of the optical fibers 608 and 609 by adjusting the gap spacing therebetween. In the illustrative embodiment shown in Fig. 6, it is useful to adhere the second waveguide holding member 5 606 to the substrate 601 after the gap spacing has been set.

Fig. 7 shows another optical switch 700 according to yet another illustrative embodiment of the present invention. The substrate 701 has grooves 702 which cooperatively engage positioning members (not shown) enabling transverse motion of the first waveguide holding member 703. The positioning members are disposed in pits 704 10 in the first waveguide holding member 703. Longitudinal grooves 705 receive positioning members (not shown) which are disposed in pits 707 in the second waveguide holding member 706. This enables longitudinal movement of the second waveguide holding member 706.

As described in connection with the illustrative embodiments above, waveguides 15 708 and 709 are selectively coupled/decoupled with the transverse motion of the first waveguide holding member 703 relative to the second waveguide holding member 706. Moreover, the longitudinal motion of the second waveguide holding member 706 enables accurate gap spacing between the first waveguide holding member 703 and the second waveguide holding member 706, thereby enabling efficient coupling between the 20 waveguides 708 and 709. After the gap spacing is adjusted, a suitable adhesive known to one of ordinary skill in the art may be used to fix the position of the first waveguide holding member and thereby set the gap spacing at the determined position.

Fig. 8 shows an optical switch 800 according to yet another illustrative embodiment of the present invention. In the illustrative embodiment of Fig. 8, a substrate 801 has transverse grooves 802 which cooperatively engage positioning members (not shown) which may be disposed in grooves 803 in the first waveguide holding member 804. As can be readily appreciated, the arrangement of the grooves 802 and 803 with the positioning member disposed therebetween enables the transverse motion of the first waveguide holding member 804. Pits 805 receive positioning members (not shown). These positioning members are disposed in grooves 806 in second waveguide holding member 807. Again, the longitudinal motion of the second waveguide member enables the coupling of waveguides 808 to waveguides 809 by setting the appropriate gap spacing between the waveguide holding members 804 and 807. Of course, the transverse motion of the first waveguide holding member 804 relative to the second waveguide holding member 807 results in the selective coupling/decoupling of waveguides 808 and 809 which enables the desired switching action.

Fig. 9 shows an optical switch 900 according to yet another illustrative embodiment of the present invention. A substrate 901 has transverse grooves 902 which cooperatively engage positioning members (not shown). The positioning members also cooperatively engage grooves 903 disposed in the first waveguide holding member 904. As can be readily appreciated, the arrangement of grooves 902 and 903 with the positioning members disposed therebetween enables transverse motion of the first waveguide holding member 904. Second waveguide holding member 905 includes a groove 906 and a pit 907. Substrate 901 includes a groove 908 and pits 909. Positioning members (illustratively microspheres) may be positioned in pits 909. These positioning

members engage groove 906. A positioning member may be disposed in pit 907. This positioning member may engage groove 908. The combination of grooves and pits in the second waveguide holding member 905 and the substrate 901 enables the longitudinal motion of the second waveguide holding member 905.

5        From the foregoing description, particularly of the illustrative embodiments shown in Figs. 2 – 9, the following generalities may be realized. The grooves and pits may be collectively referred to as depressions. These depressions may be in the substrate and in the first and second waveguide holding members. A waveguide holding member usefully has at least two depressions. The portion of the substrate opposed to the  
10      waveguide holding member (i.e. the portion of the substrate over which the waveguide holding member is disposed) usefully includes at least two depressions. Moreover, at least three of the depressions are grooves. Finally, no two opposing are pits. A similar analysis applies to the waveguide holding member disposed on the other portion of the substrate.

15      The invention having been described in detail in connection through a discussion of exemplary embodiments, it is clear that various modifications of the invention will be apparent to one having ordinary skill in the art having had the benefit of the present disclosure. Such modifications and variations are included within the scope of the appended claims.

20

**In the Claims:**

**I Claim:**

1. An optical switch, comprising:

5           A first waveguide holding member and a second waveguide holding member  
disposed over a substrate, wherein said first waveguide holding member moves relative  
to said second waveguide holding member; and  
at least one movement guiding member which guides the motion of said first  
waveguide holding member.

10

2. An optical switch as recited in claim 1, wherein said second waveguide holding  
member is stationary relative to said substrate.

15

3. An optical switch as recited in claim 1, wherein said second waveguide holding  
member moves relative to said substrate.

4. An optical switch as recited in claim 1, wherein said first waveguide holding member  
moves transversely relative to said second waveguide holding member.

20       5. An optical switch as recited in claim 1, wherein said second waveguide holding  
member moves longitudinally relative to said first waveguide holding member.

6. An optical device as recited in claim 5, wherein said transverse movement of said first

waveguide holding member selectively couples at least one waveguide of said first waveguide holding member to at least one waveguide of said second waveguide holding member.

5 7. An optical switch as recited in claim 1, wherein each of said at least one movement guiding members further comprises a positioning member disposed between a pit and a groove.

10 8. An optical switch as recited in claim 1, wherein each of said at least one movement guiding members further comprises a positioning member disposed between a first groove and a second groove.

15 9. An optical switch as recited in claim 7, wherein said pit is disposed in said first waveguide holding member, and said groove is disposed in said substrate.

10. An optical switch as recited in claim 7, wherein said groove is disposed in said substrate and said pit is disposed in said first waveguide holding member.

20 11. An optical switch as recited in claim 1, wherein said second waveguide holding member moves transversely relative to said first waveguide holding member and at least one other movement guiding member guides said movement of said second waveguide holding member.

12. An optical switch as recited in claim 11, wherein each of said at least one other movement guiding members further comprises a positioning member disposed between a pit and a groove.

5 13. An optical switch as recited in claim 11, wherein each of said at least one other movement guiding members further comprises a positioning member disposed between a first groove and a second groove.

10 14. An optical switch as recited in claim 11, wherein said pit is disposed in said second waveguide holding member, and said groove is disposed in said substrate.

15 15. An optical switch as recited in claim 11, wherein said pit is disposed in said second waveguide holding member, and said groove is disposed in said substrate.

15 16. An optical device as recited in claim 1, wherein said second waveguide holding members each include an  $mxn$  array of waveguides, wherein  $m \geq 1$  and  $n \geq 0$ .

17. An optical device as recited in claim 16, wherein said waveguides are chosen from the group consisting essentially of optical fibers and planar waveguides.

20

18. An optical switch, comprising:

A substrate having a first waveguide holding member and a second waveguide holding member disposed thereon, each of said first and second waveguide holding

members having at least three pits therein and each of said pits having a positioning member therein; and

at least two transverse grooves and at least two longitudinal grooves disposed in said substrate.

5

19. An optical switch as recited in claim 18, wherein said positioning members of said second waveguide holding member selectively engage said at least two transverse grooves.

10 20. An optical switch as recited in claim 18, wherein said positioning members of said first waveguide holding member selectively engage said at least two longitudinal grooves.

15 21. An optical switch as recited in claim 20, wherein said first waveguide holding member moves longitudinally to set a gap spacing between said first and said second waveguide holding members.

20 22. An optical switch as recited in claim 19, wherein said second waveguide holding member moves transversely along said at least two transverse grooves and said transverse movement selectively couples at least one waveguide of said first waveguide holding member to at least one waveguide of said second waveguide holding member.

23. An optical switch as recited in claim 19, wherein said second waveguide holding

member moves transversely along said at least two transverse grooves and said transverse movement selectively decouples at least one waveguide of said first waveguide holding member from at least one waveguide of said second waveguide holding member.

5

24. An optical switch, comprising:

A first waveguide holding member having at least two longitudinal grooves;  
a second waveguide holding member having at least two transverse grooves; and  
10 a substrate having at least three pits each having positioning members therein  
which engage said longitudinal grooves and at least three pits having positioning  
members therein which engage said transverse grooves.

25. An optical switch as recited in claim 24, wherein said first waveguide holding

15 member moves longitudinally to set a gap spacing between said first and said second  
waveguide holding members.

26. An optical switch as recited in claim 24, wherein said second waveguide holding  
member moves transversely along said at least two transverse grooves and said transverse  
20 movement selectively couples at least one waveguide of said first waveguide holding  
member to at least one waveguide of said second waveguide holding member.

27. An optical switch as recited in claim 24, wherein said second waveguide holding

member moves transversely along said at least two transverse grooves and said transverse movement selectively decouples at least one waveguide of said first waveguide holding member to at least one waveguide of said second waveguide holding member.

5 28. An optical switch, comprising:

A substrate having at least one longitudinal groove and at least one transverse groove;

a first waveguide holding member having at least one transverse groove; and

a second waveguide holding member having at least one longitudinal groove.

10

29. An optical switch as recited in claim 28, wherein positioning members are disposed between each of said at least one longitudinal grooves in said substrate and each of said at least one longitudinal groove in said second waveguide holding member.

15

30. An optical switch as recited in claim 28, wherein positioning members are disposed between each of said at least one transverse grooves in said substrate and each of said at least one longitudinal groove in said first waveguide holding member.

20

31. An optical switch as recited in claim 28, wherein said substrate further includes at least one pit.

32. An optical switch as recited in claim 28, wherein said second waveguide holding member further includes at least one pit.

33. An optical switch as recited in claim 28, wherein said first waveguide holding member further includes at least one pit.

5 34. An optical switch, comprising:

At least one waveguide holding member disposed on a substrate;

at least two depressions disposed in each of said at least one wavguide holding members; and

at least two depressions disposed in said substrate, wherein at least three of said

10 depressions are grooves and no two opposing depressions are pits.

### **Abstract of the Disclosure**

An optical switch includes a first waveguide holding member and a second waveguide holding member disposed on a substrate. The first waveguide holding member moves relative to the second waveguide holding member. A movement guiding member guides the motion of the first waveguide holding member and the substrate.

Advantageously, the first waveguide holding member moves transversely relative to the second waveguide holding member. The traverse motion enables selective coupling between a waveguide in the first waveguide holding member and a waveguide

10 in the second holding member. Through this transverse motion of the second waveguide holding member, an optical switching action may be implemented.

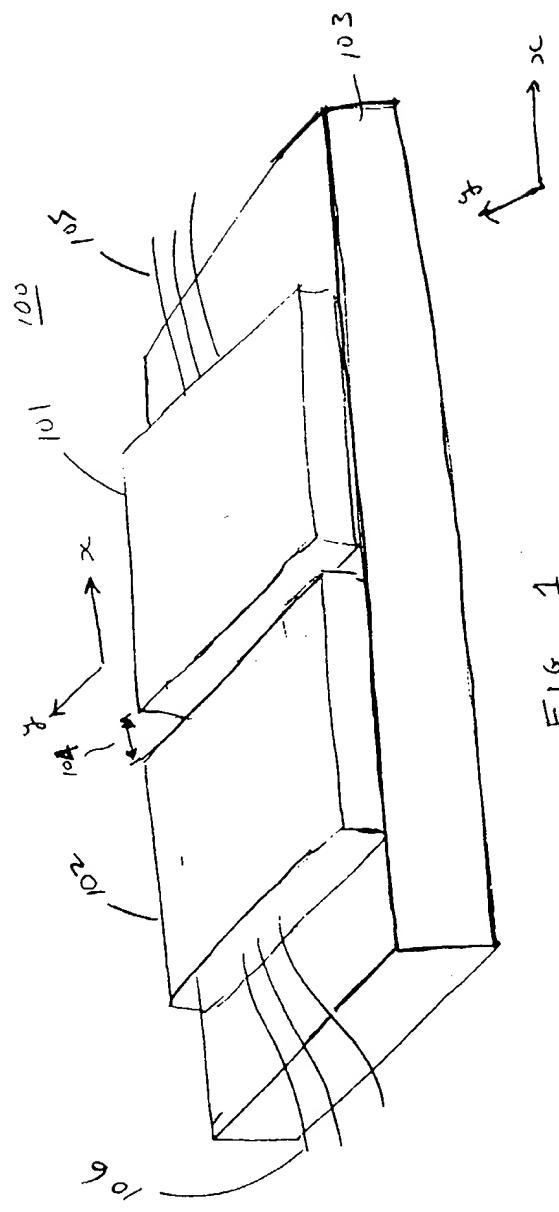


Fig. 1.

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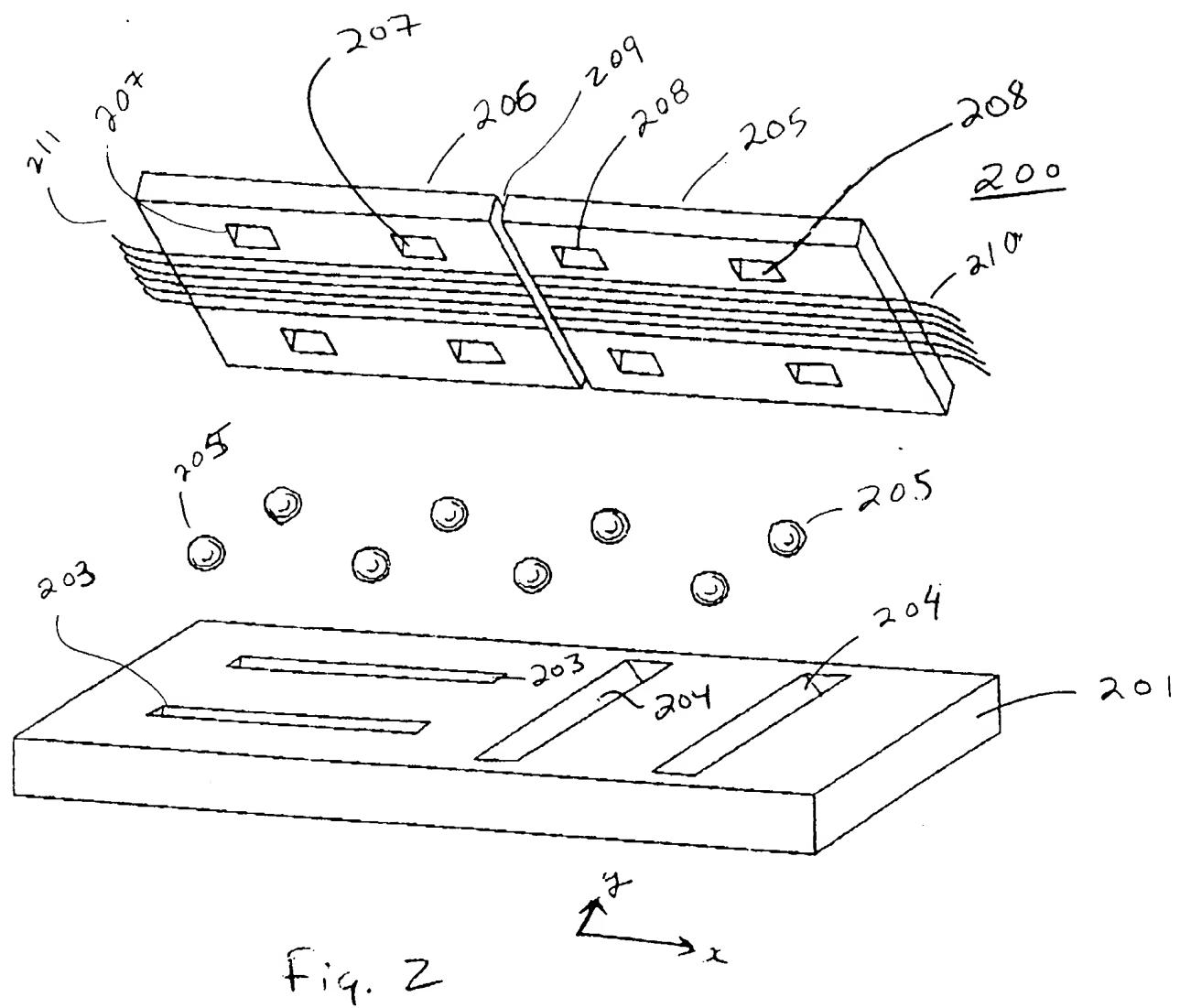


Fig. 2

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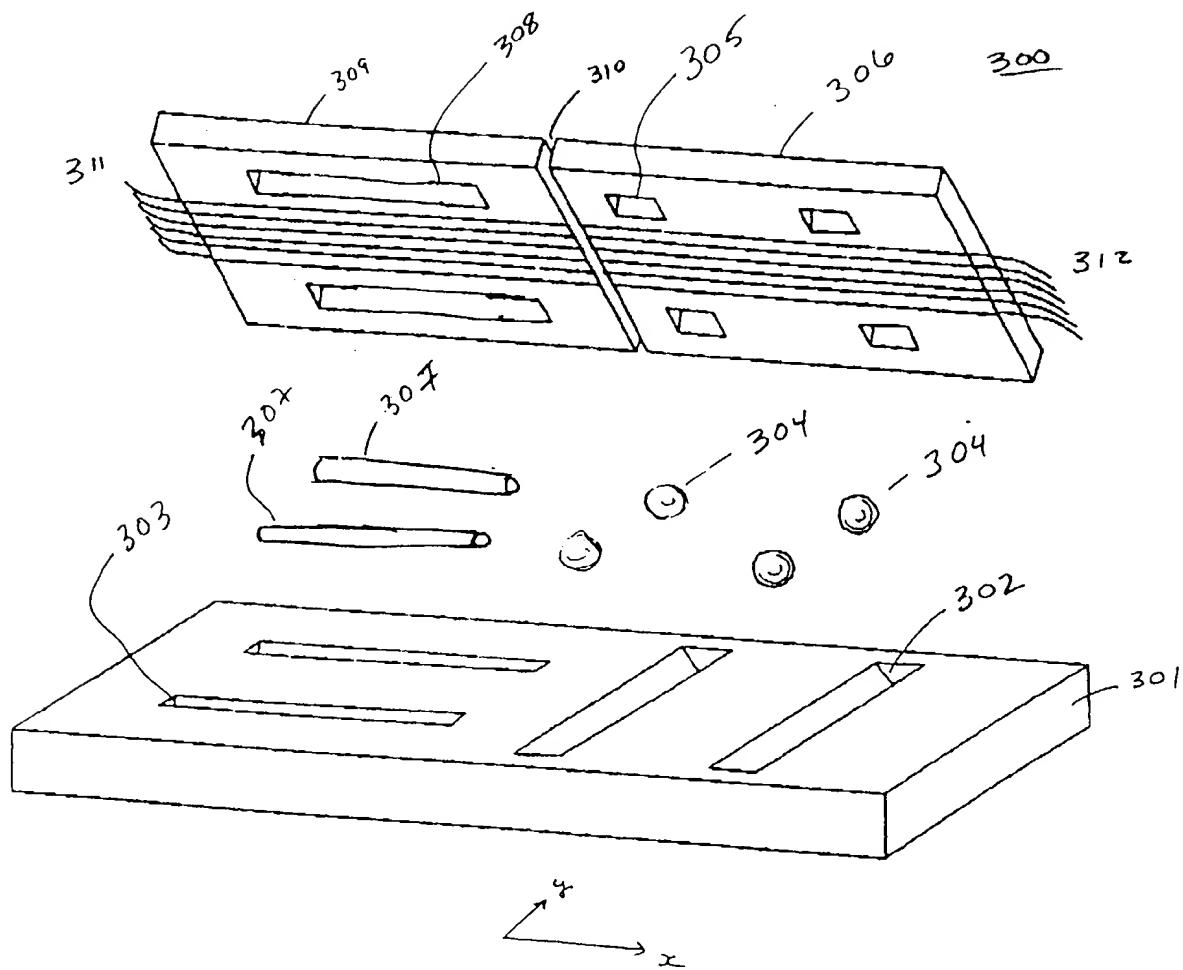


Fig. 3

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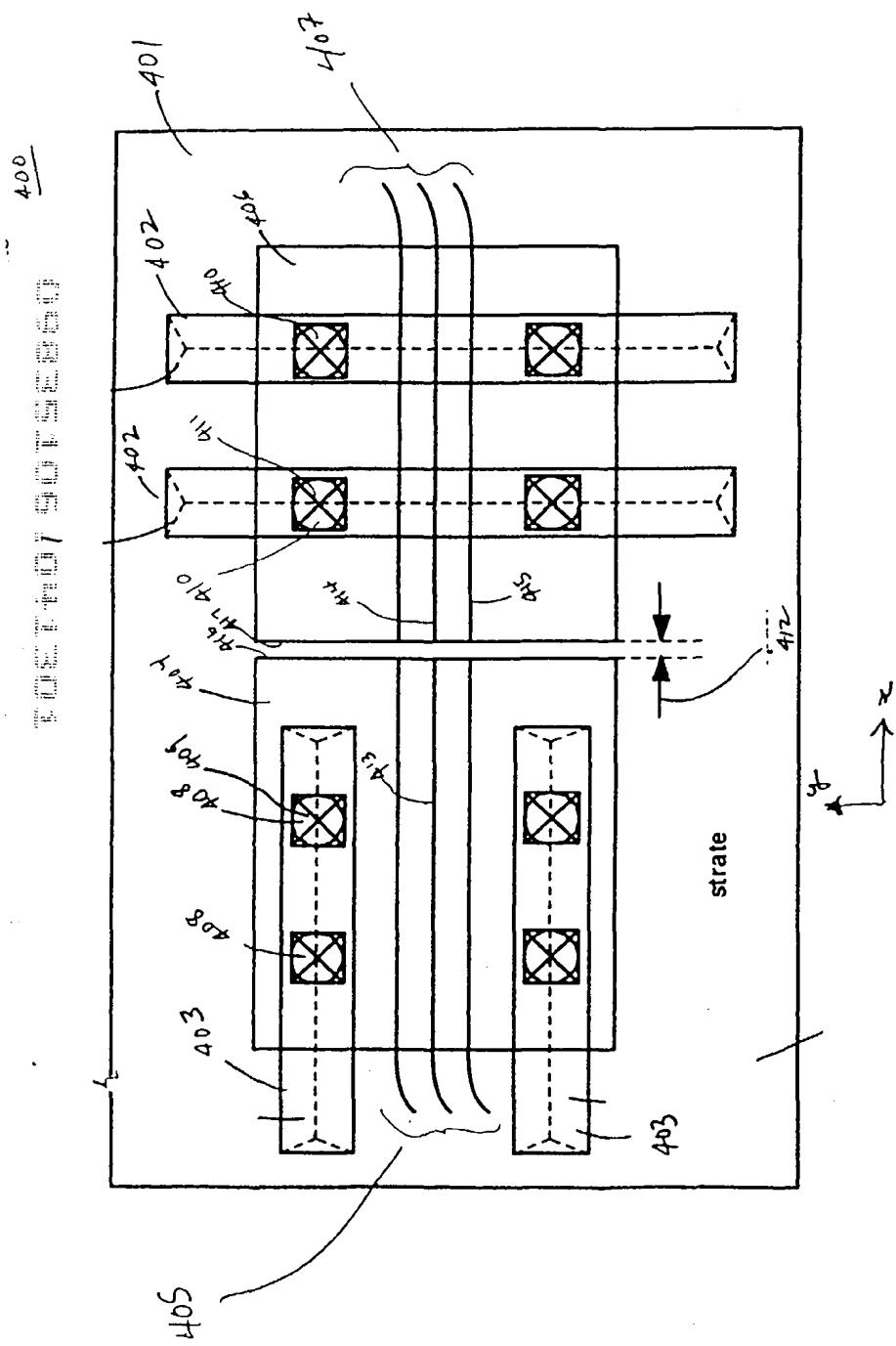


Fig. 4

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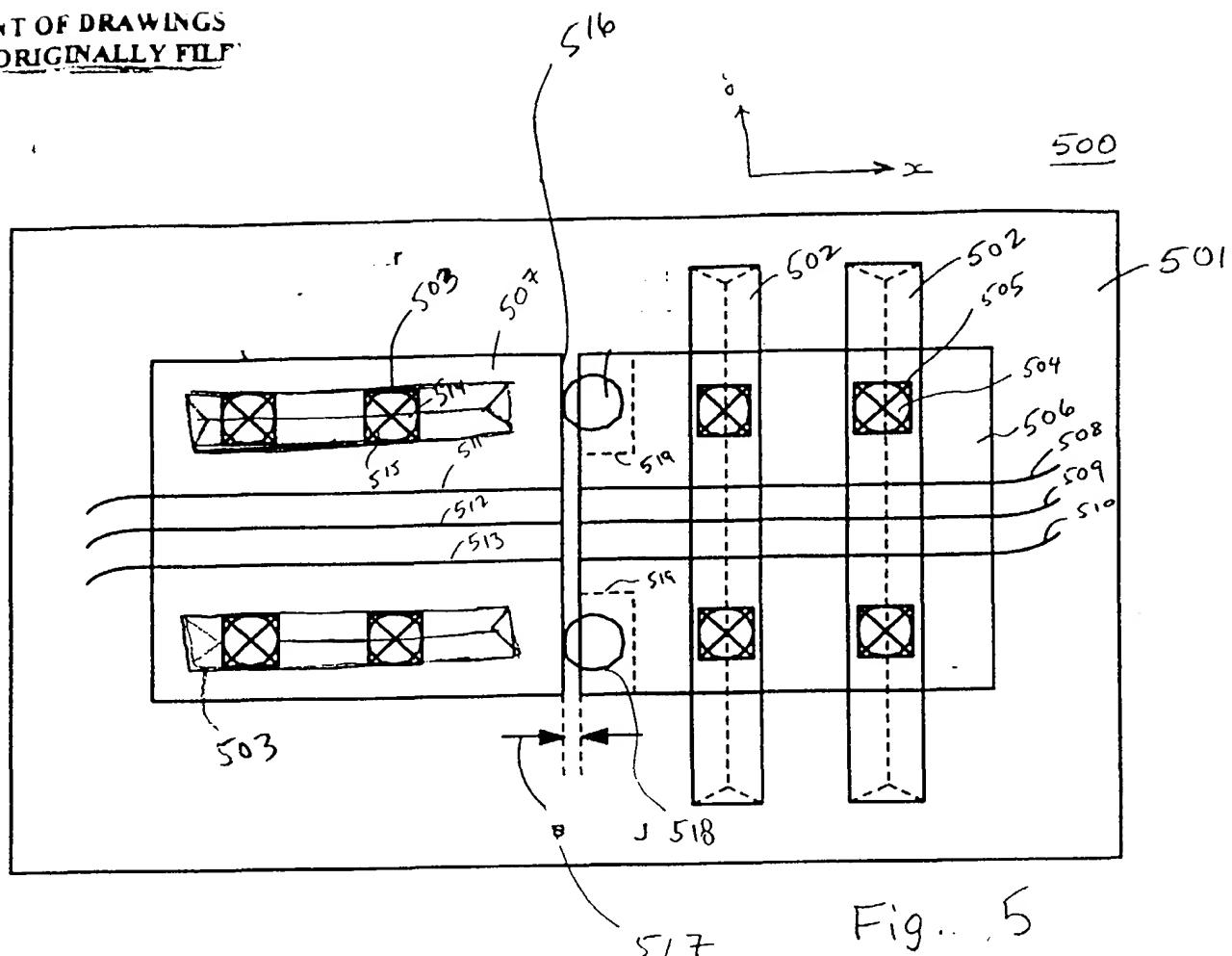


Fig. 5

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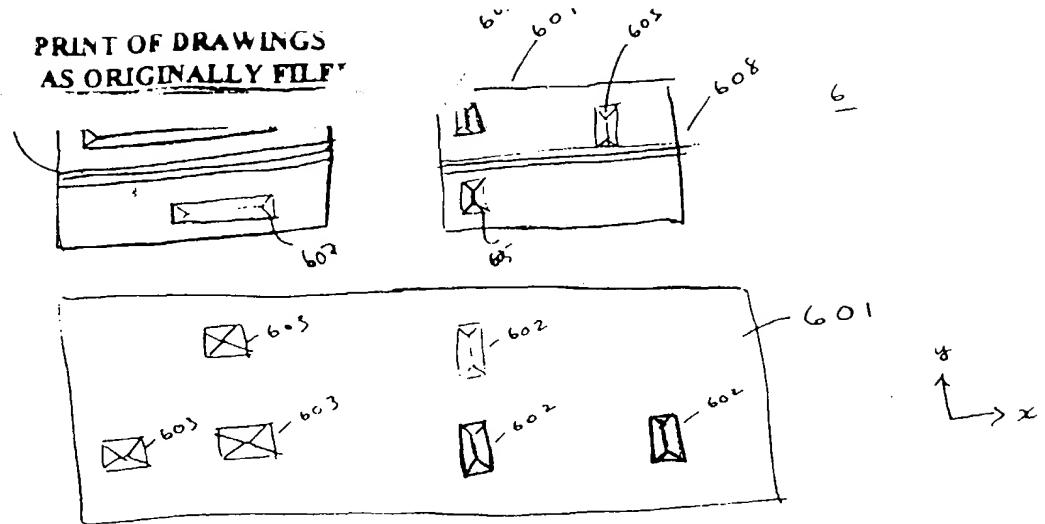


Fig. 6

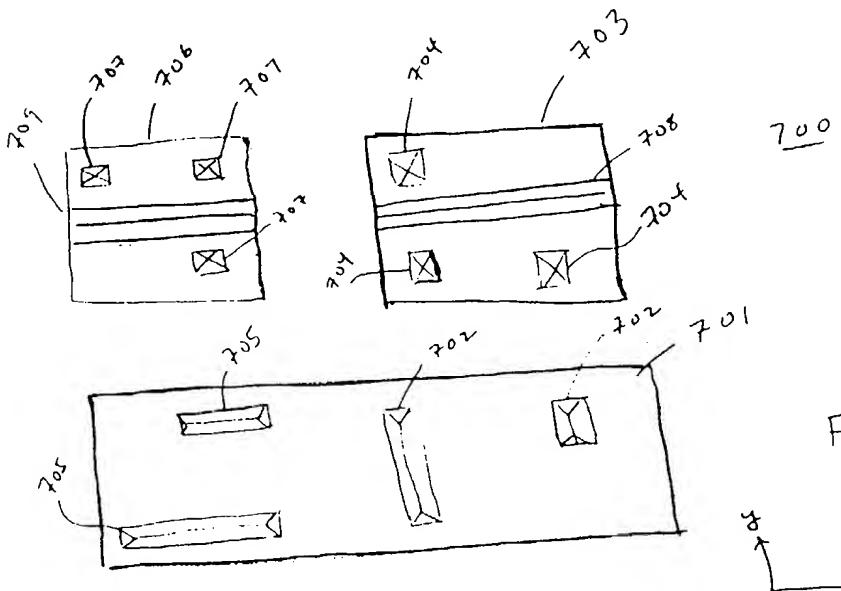


Fig. 7

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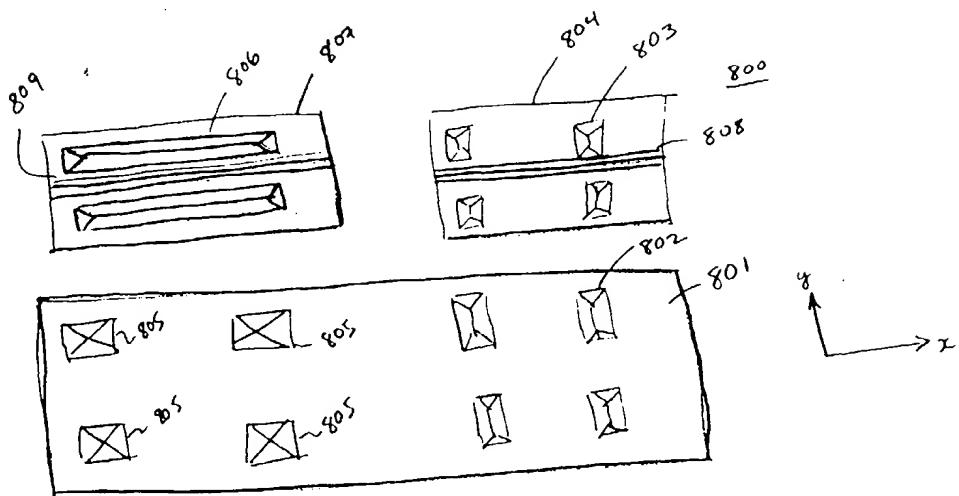


Fig. 8

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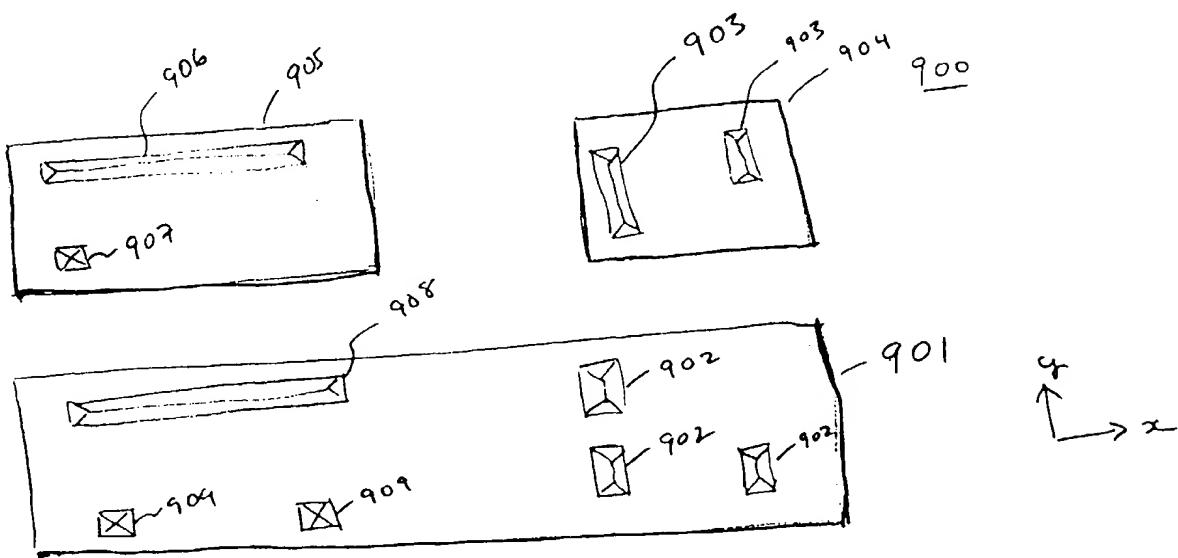
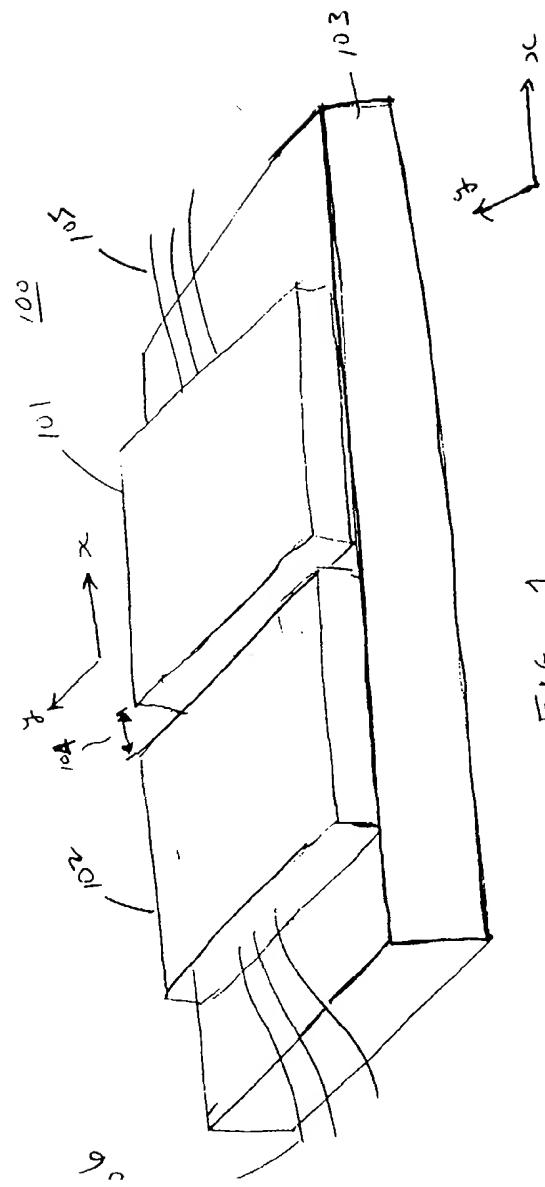
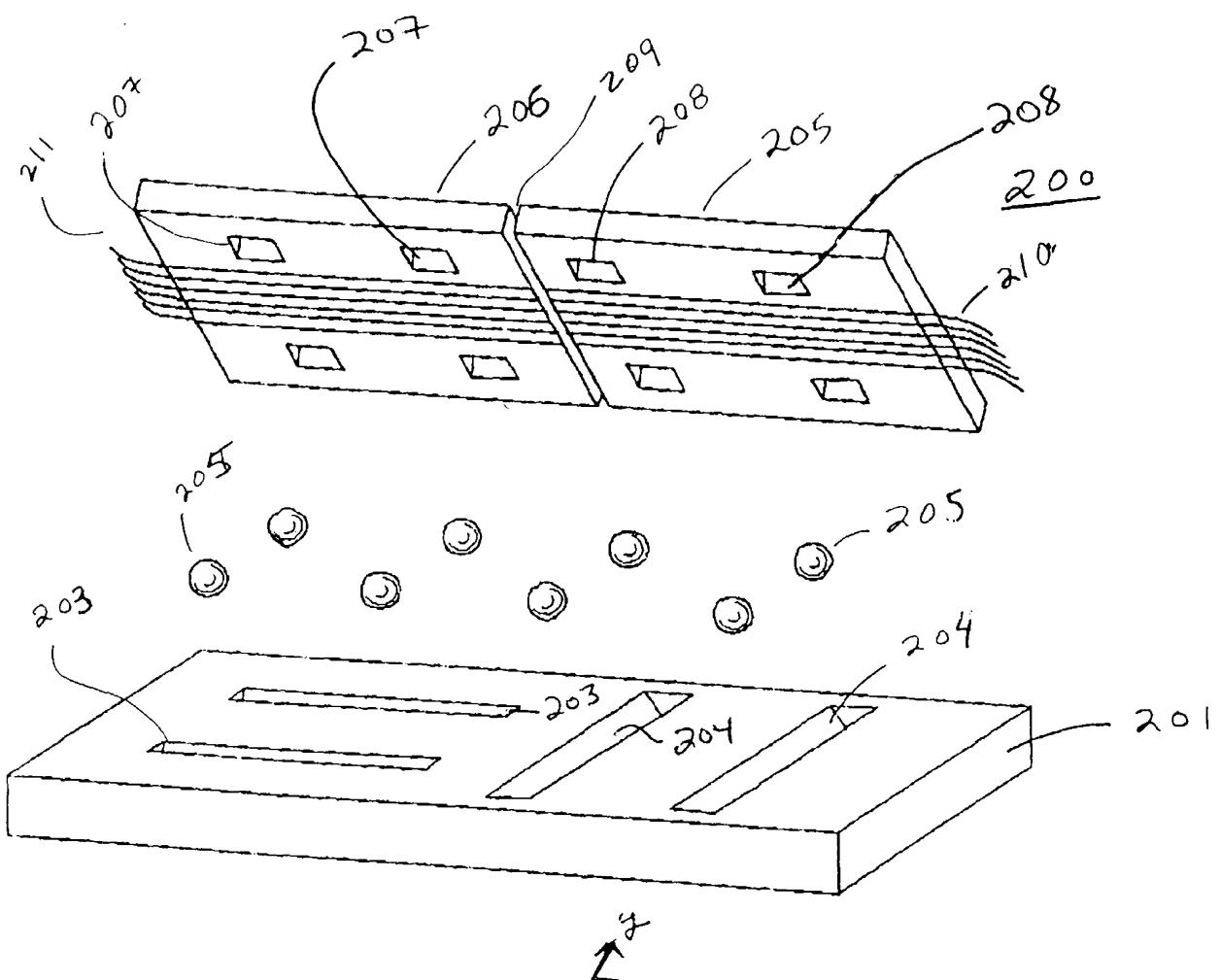


Fig. 9





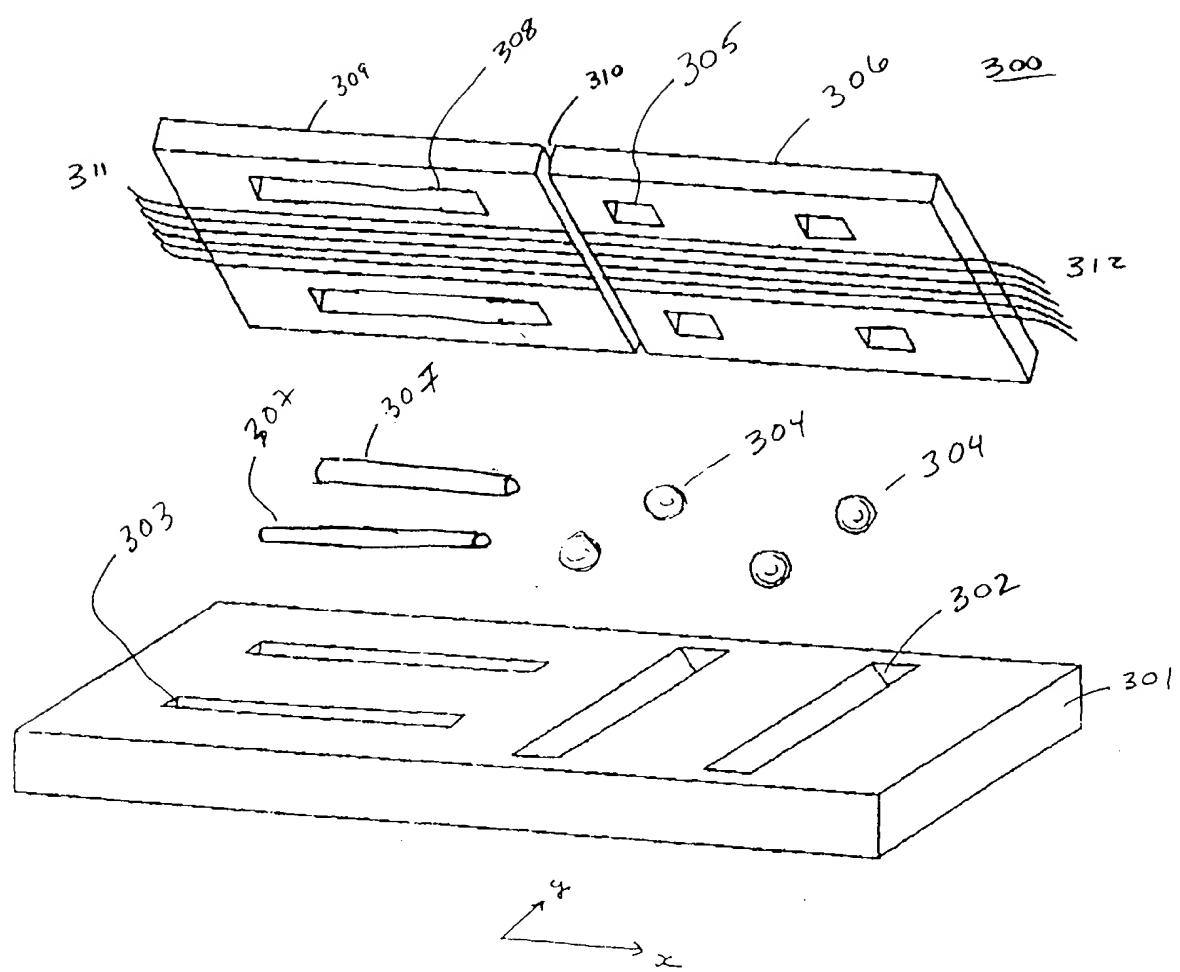


Fig. 3

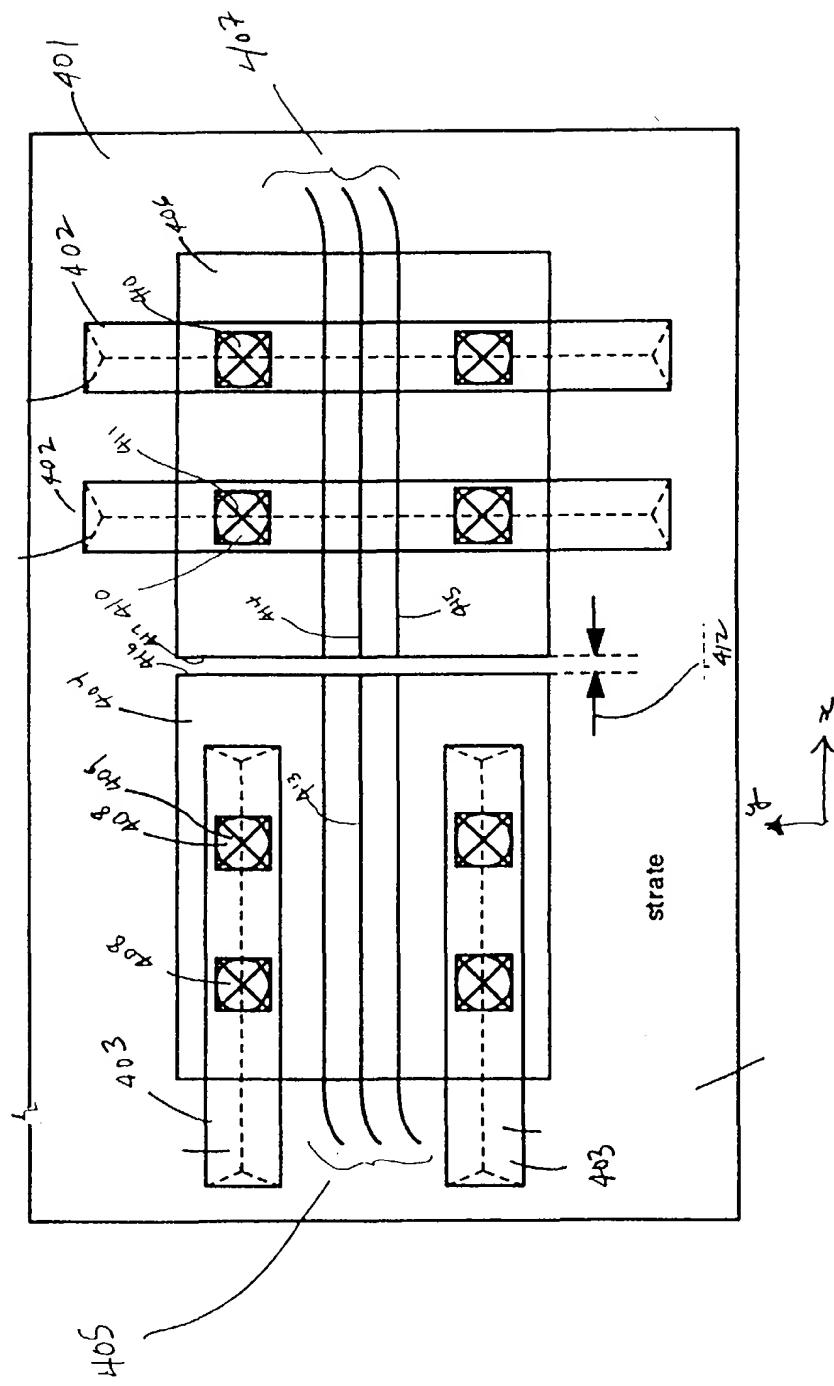
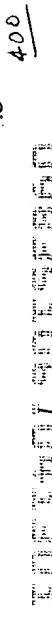


Fig. 4

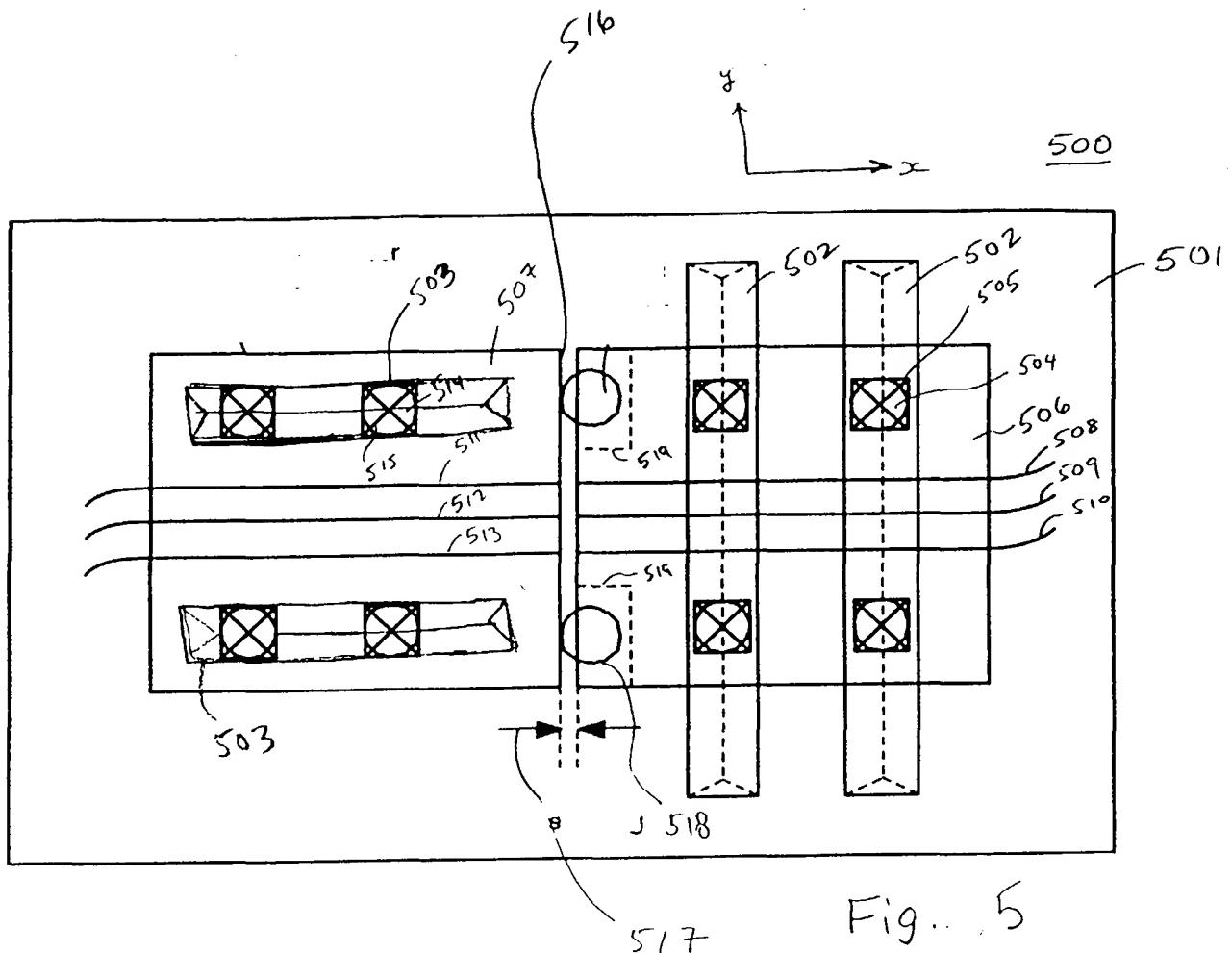


Fig. 5

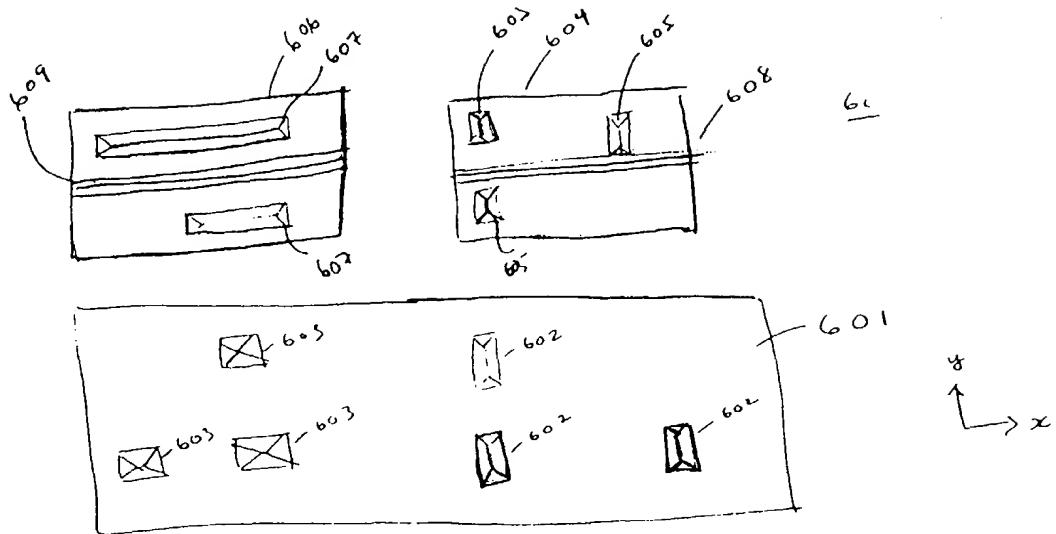


Fig. 6

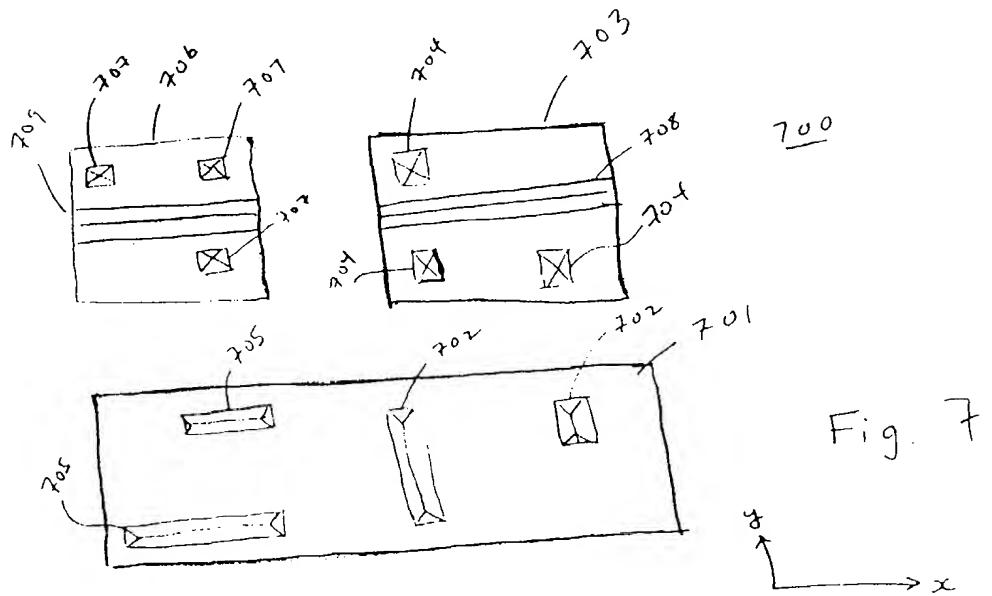


Fig. 7

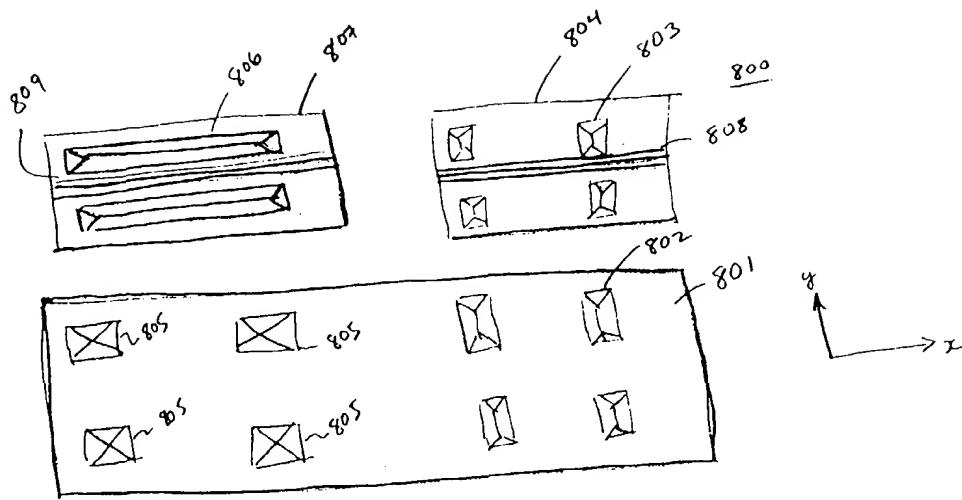


Fig. 8

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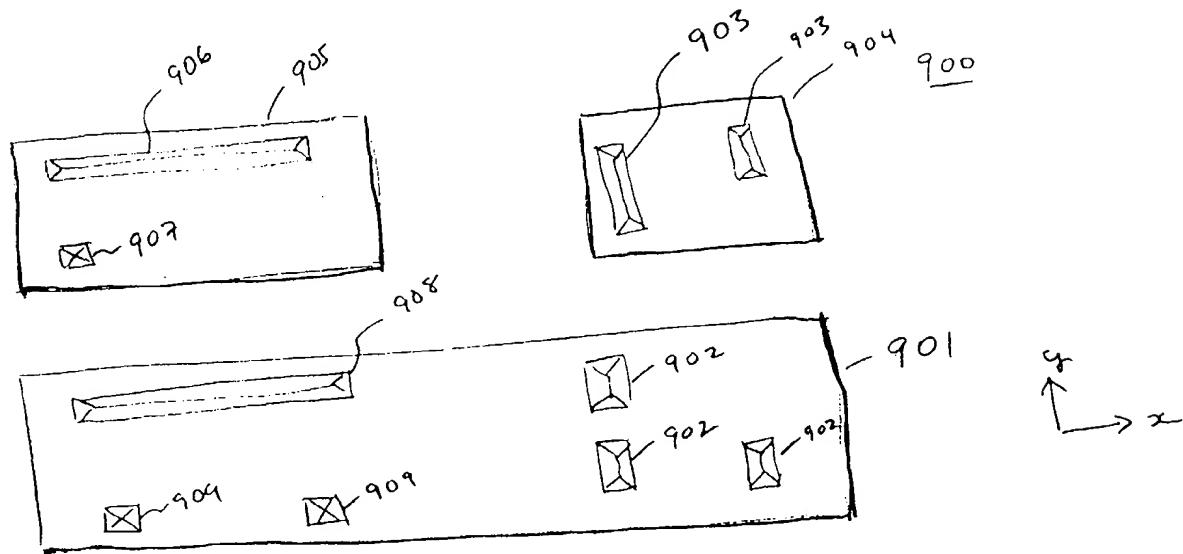


Fig. 9